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SULPHUR

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Focus on Brazil

Sulphur recovery project listing

Tower design in acid plants

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BCInsight

Southbank House, Black Prince Road
London SE1 7SJ, England
Tel: +44 (0)20 7793 2567
Fax: +44 (0)20 7793 2577
Web: www.bcinsight.com
www.bcinsightsearch.com

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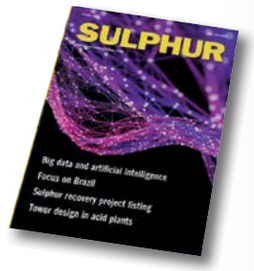
Southbank House, Black Prince Road
London SE1 7SJ, England

Tel: +44 (0)20 7793 2567

Fax: +44 (0)20 7793 2577

Web: www.bcinsight.com
www.bcinsightsearch.com

Still at sea



I am writing this freshly returned from The Sulphur Institute's annual World Sulphur Symposium in Prague, a fuller account of which is on pages 31-32 of this issue. The gathering was the usual mix of interesting presentations and conviviality, but what struck me this time was that the topic which seemed to come up in conversation more than any other was the effect of the International Maritime Organisation's 0.5% limit on sulphur content of bunker fuels, which is due to come into force on January 1st next year.

The topic was covered by a presentation by Adrian Tolson of the aptly named 2020 Marine Energy consultancy. He rehearsed the various options for compliance – switching to low sulphur bunker fuels, converting ships to run on alternative fuels such as LNG, methanol or hydrogen, installing onboard exhaust scrubbing systems which remove sulphur dioxide from the ship's engine exhaust, or simply not complying. The latter had originally been assumed to be quite a large segment, but moves by the IMO to switch enforcement from flag states to port states and statements by insurers that they would not insure ships which failed to comply with the regulations seem to now have closed most of that loophole. In the meantime, the uptake of scrubbing systems has been relatively small and mostly confined to the largest vessels, representing only about 10% of bunker fuel demand, as the cost of installation is relatively constant across ship types, and thus becomes prohibitive for smaller ships. Likewise alternate fuels have seen only minimal uptake, and come next January, most ships are going to be relying on sourcing sufficient low sulphur fuel to operate.

> **Most ships are going to be relying on sourcing sufficient low sulphur fuel to operate.**

This means that – on a global basis – refiners are going to have to be producing 3 million or more barrels per day of low sulphur bunker fuel by January (depending on non-compliance rates), and also converting or finding a buyer for up to 2.5 to 3 million barrels per day of excess high sulphur fuel oil (HSFO). What I found most interesting about this potential dilemma was that the views of the various consultants present at the meeting as to what this would mean for refinery sulphur outputs were widely divergent – predicting anything from an extra 400,000 t/a of sulphur in 2020-21 to more than 2 million t/a – quite a spread of opinion! There are a great many factors at play which could influence matters, from the availability of spare coking capacity (mainly a factor for US refiners) and how much suitable blendstock can be sourced, to whether it is economical to bring back on-stream idled refineries capable of producing low sulphur fuel oil, and from availability of sweet crude feedstock on the international market to the willingness of power markets to buy HSFO to burn in power plants. Refiners rarely have much space to store excess sulphur, so stockpiling any extra supply may not be an option. This uncertainty means that the sulphur market in 2020 could be facing a glut or a trickle of extra sulphur, and may not know which until it happens.

Richard Hands, Editor

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Price trends

MARKET INSIGHT

Meena Chauhan, Head of Sulphur and Sulphuric Acid Research, Argus Media, assesses price trends and the market outlook for sulphur.

SULPHUR

The main focus in the sulphur market through March and into April was second quarter contract negotiations. With China still on the sidelines and little spot interest, price resistance in major markets and a lacklustre downstream phosphates market, all signs pointed to decreases compared with first quarter pricing. The majority of contracts were settled at decreases ranging between $20-30/t with the only exception to this in NW Europe as Benelux contracts largely rolled over.

Global sulphur prices appeared to reach a period of stability in April following a slight rebound in March/April. The weakness in the processed phosphates pricing weighed heavy on sentiment however and a meaningful recovery has yet to emerge.

In the Middle East, monthly producer price postings for April reflected the continued weak sentiment following the slight stability seen in March. Muntajat announced its April Qatar Sulphur Price (QSP) at $103/t f.o.b., a $5/t decrease on March. The producer's tender for 35,000 tonnes loading in April was awarded in the high-$100s/t f.o.b. State owned ADNOC in the UAE set its price at $105/t f.o.b. Ruwais for liftings to the Indian market – a $3/t drop on a month earlier. Over in Kuwait, KPC set its April price at $102/t f.o.b. Shuaiba – a drop of $4.50/t on its March price. The producer started posting a monthly price from January this year – with its exports set to rise in line with the Clean Fuels Project in Kuwait. Additional sulphur trade is expected as this project ramps up in late 2019/2020.

African demand for sulphur is mixed with North Africa continuing to see an uptick as OCP expands its processed phosphates production capacity while end user Foskor in South Africa faced strike action. January sulphur trade to Morocco was up 63% year on year to 689,000 tonnes – led by a surge in shipments from the UAE and Saudi Arabia. For South Africa, prospects remain in question.

Trade data shows a 32% drop in sulphur imports to South Africa in January-February 2019 compared with a year earlier at just 103,000 tonnes. The drop was reflected in trade from Kazakhstan, down by 29% while there was a slight uptick in volumes from Saudi Arabia. We expect to see imports ticking up into 2020 however to meet growing demand for sulphur in the DRC. Glencore's Kamoto Copper Company's (KCC) sulphur burner is expected online in the first quarter of next year and will significantly impact sulphur and sulphuric acid trade in the region. Meanwhile planned maintenance at Foskor's Richard's Bay facilities at the end of April is expected to last through the month of May and will likely further stifle sulphur demand to the consumer.

Chinese demand question remains a major market theme due to the period of slow pricing and uncertainty surrounding future growth in domestic sulphur demand. Spot prices in China have dropped around 12% since the start of the year on the high end of the range to $118/t c.fr in mid April. Towards the end of the month, small lots deals were heard being concluded in the $120s/t c.fr range. Larger volumes were still pegged in the high $110s/t c.fr however. There appears to be some optimism with local traders holding tonnes, waiting for the market to firm, should buyers return to the market in the coming weeks. Port stocks totalled around 1.3 million tonnes in mid-April. Inventories at Nantong port were run down at the start of the month following the announcement in 2018 that sulphur discharge would cease at its Langshan berth at the end of 2018. China imports during January – February totalled 2.03 million tonnes, a 13% increase on a year ago. Molten sulphur shipments to China also saw an uptick from East Asia. Domestic production of sulphur in China continues to rise, with around 400,000 tonnes of additional supply expected to come online in 2019 from new refining capacity.

Maintenance turnarounds in India left buyers broadly on the sidelines in March and first half April. The end of the month is expected to see some uptick in spot interest that will test prices. Spot prices have dropped by around 16% since the start of the year, in line with international developments. Indian sulphur imports saw a rise in January year on year, up by 33% at 133,000 tonnes. The UAE was the leading supplier as usual at 97,000 tonnes.

In North America, Tampa quarterly contracts settled at $88/lt for molten sulphur, down by $21/lt on the first quarter, on the back of weakness in spot pricing in recent months. Vancouver spot prices dipped below $100/t f.o.b. in April in the mid/high $90s/t on the back of downward pressure from international developments, buyer resistance in China and weak downstream markets. This compares to levels a year earlier up into the low $120s/t f.o.b. Recent local news in Alberta following the provincial elections may be deemed positive for the oil sector and potentially sulphur as a result of a swing to the United Conservative Party (UCP). The carbon levy will likely be challenged as a result of this shift as well as a reduction in corporate tax.

SULPHURIC ACID

The global sulphuric acid market continued its softer trend through April, with prices dropping $20-25/t since February for spot pricing in NW Europe to $55-65/t f.o.b. The decrease has come on the back of deals concluded in Latin America, with offers in tenders in Brazil also declining. A slowdown has been seen as the market balance has become less extreme, Chile remains well served with contract and spot cargoes booked. The downstream markets have also impacted market prices and the softer footing in the elemental sulphur market is also taking its toll on sulphuric acid sentiment. On the contract front in Europe, settlements were noted at rollovers to slight increases, with the maintenance schedule a key bull in negotiations.

Firm freight rates have been seen in shipments to Chile, potentially propping up prices in the short term. Major end users in Chile were noted as broadly covered in mid-April and spot prices dipped down to $115-120/t c.fr, down from $135-145/t c.fr in February and marking a steady downward trend. Interest is expected to emerge for the upcoming quarter but in the meantime buyers reported ample stocks and a slowdown in demand due to weather related issues. Codelco's Chuquicamata smelter remains offline with a timeline yet to become clear for a restart. On the import front, January-February 2019 trade to Chile was up by 25% year on year to 691,000 tonnes. Chinese supply surged to 206,000 tonnes while Peruvian supply dropped 44% to 127,000 tonnes. Chile is expected to remain in deficit for the short term outlook, supporting trade and pricing. The long term view remains for Chile to move from deficit to surplus, but this remains several years away.

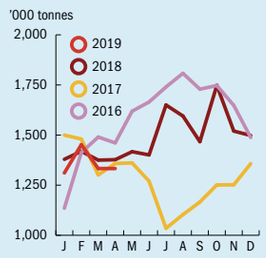
The Brazilian market has seen a slowdown, alongside the lacklustre processed phosphates market. Local stocks were heard to be healthy in mid-April, with demand largely covered. The next round of tenders is expected during May. On spot pricing, the range dropped to $100-110/t c.fr Brazil, down around $30/t on February levels. The recent announcement from Mosaic to idle its phosphate rock mines in Brazil is likely to impact acid demand in the short term. However, we expect to see increased finished phosphate fertilizer shipments from the US to cover the shortfall, with acid demand potentially ticking up in North America as a result.

In the US, the market balance eased in the West, on the back of the restart of the Kennecott smelter back to regular operating levels and increased acid availability. Imports of acid dropped 10% in January-February year on year, with supply in Canada tight. Mexican trade saw an uptick to 43,000 tonnes. Average prices into the US Gulf were assessed at $100-110/t c.fr in April, below the $120s/t c.fr seen earlier in the year.

Ongoing market focus remains on Morocco in the acid market with little urgency seen from major phosphates producer OCP to secure spot cargoes for the second quarter. Up to four contract shipments were booked from NW Europe to arrive during the second quarter to the buyer. Delivered prices to North Africa dropped below the $100/t level, reflecting the downturn in the international market. Argus analysis shows first quarter 2019 acid imports into Jorf Lasfar port tallied 349,000 tonnes, down 14% year on year. Many European producers have been diverting volumes to other markets including the Americas due to strong demand and tight supply in the US.

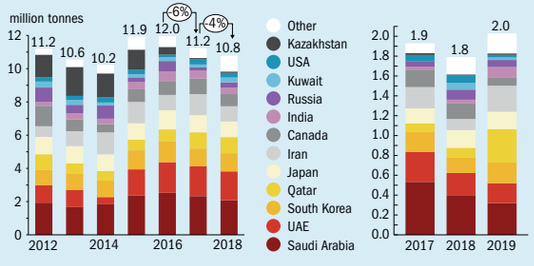
Exports of acid from China remain a consideration for the future of acid trade and pricing. In 2018, China became a net exporter of sulphuric acid for the first time in history. So far in 2019, this trend has continued. February acid exports exceeded imports on the back of a weak domestic market and pockets of regional tightness. February exports totalled 131,000 tonnes, with shipments to major market Chile at a record high of 91,000 tonnes – up from zero just a year earlier.

Fig. 1: **China sulphur port inventory, 2016-2019**



Source: Argus Media

Fig. 2: **China sulphur imports**



Source: Argus Media/China Customs

Price indications

Table 1: **Recent sulphur prices, major markets**

Cash equivalent	November	December	January	February	March
Sulphur, bulk ($/t)					
Adnoc monthly contract	173	155	127	108	108
China c.fr spot	176	153	117	133	135
Liquid sulphur ($/t)					
Tampa f.o.b. contract	140	140	109	109	88
NW Europe c.fr	138	150	133	130	130
Sulphuric acid ($/t)					
US Gulf spot	103	100	100	100	105

Source: various

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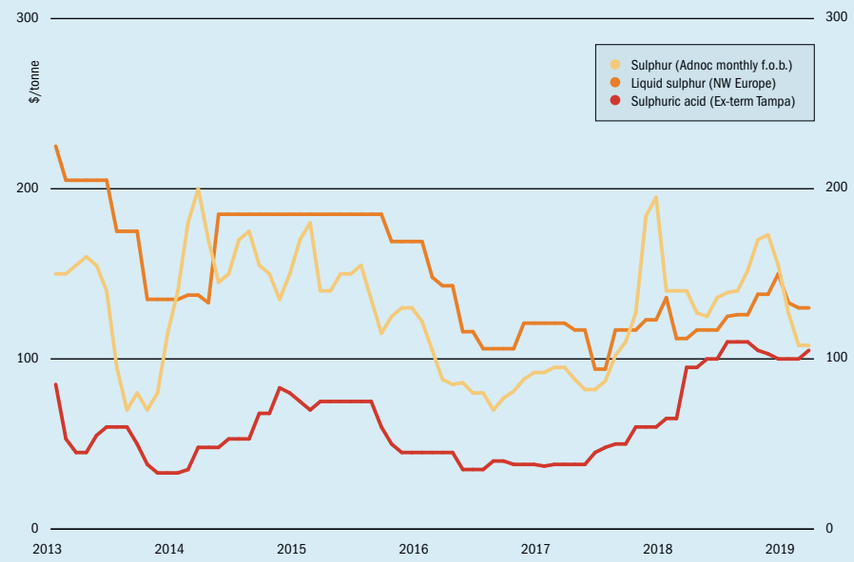
Market outlook

Historical price trends $/tonne



Source: BCInsight

SULPHUR

- Developments in the phosphates market will be a driving factor for the outlook for sulphur. Phosphate producers in China were heard cutting output in April, reducing sulphur consumption temporarily. Planned maintenance turnaround at major end user facilities in the south of the country have also impacted sulphur uptake recently.
- Spot activity in Brazil and North African markets has been limited, any upturn in these markets would help support a price recovery for sulphur. Major end user OCP is understood to be covered through contract deliveries for the remainder of the quarter. Sulphur arrivals from January to the start of May are expected total 1.58 million tonnes – a 9% increase on a year earlier.
- Supply side factors remain broadly stable for the short term, with additional supply expected from 2020 onwards in the Middle East and Asia.
- Expectations are for increased river exports from Russia in 2019 following the reopening of the Volga Don waterway at the end of March. Kashagan supply continues to move from the port of Ust Luga, adding to competition in global trade.
- Indian demand in the coming weeks may provide a boost to the market as the maintenance schedule at phosphate producers comes to an end. Domestic supply remains ample however and may stifle import business.
- **Outlook:** Buyers and producers face a standoff as producers try and tip the balance towards recovery while end users remain on the sidelines as further erosion may occur. The lacklustre processed phosphates market continues to erode sentiment with an uptick awaited to provide support to demand side factors for sulphur consumption.

SULPHURIC ACID

- Exports from China remain a bear in the market outlook but softening prices may prove prohibitive to some producers with high logistics costs in moving acid from inland plants to ports. Two Lions remains the largest exporter.
- Vedanta continues to face issues with the legal battle to reopen its Tuticorin smelter in Tamil Nadu. The smelter has been offline for over a year and has significantly impacted acid pricing and trade to India. The continued absence of the acid from the smelter remains a supportive factor for the Asian market.
- The slow sulphur and tepid phosphates markets remain bearish factors for acid in the short term.
- The turnaround schedule and outages at smelters in the second half of 2019 may provide regional support to pricing during periods of tightness.
- **Outlook:** Global acid prices may ease further during this period of slow demand but a floor is expected once buyers return to the spot market. Chile, Brazil and Morocco remain key import markets while developments in China export trade will also influence market direction.

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WORLD

Low sulphur shipping fuel investments top $1 billion

BP has put the total investment cost by refineries in meeting the new MARPOL low sulphur fuel requirements at $1 billion to date. Speaking at the Fujairah Bunkering and Fuel Oil Forum in the United Arab Emirates, Eddie Gauci, BP's global head of marine fuels also indicated that investments would likely continue beyond 2020, when the new maritime fuel standards come into force. Markets are braced for considerable disruption around the changeover period, which the International Energy Agency calls "the most dramatic [change] ever seen to product specifications", and Gauci said that he believed that a lot of fuels would be in storage, including floating storage, in advance of the January 1st deadline, "until the land-based infrastructure establishes some kind of equilibrium that's in tune with what grades of fuel are called for in particular locations." He also commented that there was a "strong supply" of compliant low sulphur fuel oil available in hub locations such as Rotterdam, Singapore and Fujairah. BP announced in March that it would be offering its own Very Low Sulphur Fuel Oil (VLFSO) grade worldwide from the end of the year, following on from similar announcements from Shell and ExxonMobil.

GERMANY

Hapag-Lloyd to pass sulphur costs on to customers

Hamburg-based Hapag-Lloyd, the world's fifth-largest shipping company, has become the latest to indicate that it will have to pass the costs of the new International Maritime Organisation (IMO) sulphur regulations on to customers. The new IMO rules on sulphur content of shipping fuels come into force on January 1st 2020, and specify that all bunker fuels must contain less than 0.5% sulphur by weight, down from the previous cap of 3.5%, in order to reduce sulphur dioxide emissions. In its 2018 annual report, Hapag-Lloyd has estimated that compliance costs, in terms of additional fuel costs and the cost of installing scrubbing equipment will cost the firm $1 billion a year from 2020 onwards, and the company says that it will be introducing a new surcharge to cover that.

INDIA

Another contract awarded for HPCL Visakh refinery upgrade

French company Axens says that it has been selected to provide technologies as part of the upgrade of Hindustan Petroleum Company Ltd (HPCL)'s 9 million t/a (167,000 bbl/d) Visakh refinery at Vishakhapatnam in Andhra Pradesh state. Axens' scope includes the provision of process licenses, catalysts and adsorbents, proprietary equipment, training and technical services, according to the company. HPCL jointly operates the refinery with the government of India, and is upgrading it to produce Bharat Stage VI (Euro-VI) compliant products in the Visakh Refinery Modernisation Project (VRMP). Other contracts have been previously awarded to Chevron Lummus Global to license their vacuum residue upgrading technology, while heavy equipment works are being carried out by Larsen and Toubro – the latter says that it has completed installation of a 1,900 tonne hydrocracker reactor as part of the vacuum residue upgrade section, and is expecting delivery of heavy equipment items soon for the next phase of work. The VRMP project will take refinery output to 300,000 bbl/d by July 2020.

The project includes installation of two 360 t/d sulphur recovery units (720 t/d total, including tail gas treatment), two 540 t/h amine generation units, and a 112,000 t/a sulphur recovery LPG treating unit.

BPCL to expand cracking plant

India's Bharat Petroleum Corp Ltd (BPCL) says that it plans to build a 3 million tonne/year residual fluidised catalytic cracking plant at its Mumbai refinery complex by 2022. The $1 billion project forms part of the refinery modernisation plant, replacing both the existing catalytic cracking unit and fluidised catalytic cracking unit. The project includes a fractionator and unsaturated gas plant; a regenerator flue gas scrubber; an unsaturated liquefied petroleum gas treating unit; a propylene recovery unit, and a sulphur recovery unit.

UNITED STATES

Honeywell and Wood to cooperate on digital refinery technology

Honeywell UOP and Wood have agreed to work together via the Honeywell Connected Plant platform to commercialise digital services for refiners and petrochemical manufacturers. The two companies say that they will develop Connected Plant capabilities for Wood's Foster Wheeler SYDECSM delayed coking technology which converts heavy oil fractions into fuel-range distillates and other products. Honeywell Connected Plant is designed to provide oil and gas customers with higher levels of safety, reliability, efficiency and profitability, applying proprietary process knowledge and troubleshooting experience to recommend operational adjustments and assisting plants to run more consistently and at the top of their performance capability.

"Honeywell is a strategic partner in the connected plant space and together, we are ideally positioned to deliver the digital services our customers need," said Bob MacDonald, CEO of Wood's Specialist Technical Solutions business. "With this partnership, our customers will experience improved profitability through software-enabled services that guide the efficient operation of Delayed Coking and other related processes."

Marathon Petroleum to upgrade Galveston Bay refinery

Marathon Petroleum says that it will spend $1.2 billion upgrading its Galveston Bay refinery complex from 2019-2022 as part of an ongoing integration and modernisation programme for its Texas refineries, including the adjacent Texas City refinery, which it bought from BP for $2.4 billion in 2013. The so-called called South Texas Asset Re-positioning (STAR) program is designed to expand crude processing capacity by 40,000 bbl/d and allow for more production of ultra-low sulphur diesel, distillates and gas oil to meet US Environmental Protection Agency's Tier 3 gasoline sulphur standards and the upcoming IMO marine sulphur rules. Fluor has been awarded the EPC contract for the upgrade.

ExxonMobil's Jurong refinery at Singapore.

SINGAPORE

Exxon to expand Singapore refinery

ExxonMobil says that it has made a final investment decision on its plans to increase production at its Singapore refinery to produce higher value products and expand lubricant base stocks production. The expansion, scheduled to be completed by 2023, will increase capacity of low sulphur fuels by 48,000 bbl/d, including 0.50% sulphur bunker fuel to achieve compliance with the requirements of the new IMO 2020 regulations. The investment will add 20,000 bbl/d day of base stocks capacity, which includes EHCTM 50 and EHCTM 120 grades, in addition to a new high-viscosity Group II base stock to meet increasing demand in the Asia-Pacific region. The company says that engineering, procurement and construction (EPC) activities at the site have already begun, with Técnicas Reunidas overseeing the new process units, and Wood Group interconnecting pipelines and supporting infrastructure. There is also an agreement with Linde pending to upgrade residue from the site to hydrogen and synthesis gas.

In relation to the introduction of the global 0.50% sulphur cap, ExxonMobil has already confirmed supply of 0.50% sulphur grades at the ports of Antwerp, Rotterdam, Genoa and Marseilles in Europe, along with Singapore, Laem Chabang in Thailand and Hong Kong. Other supply locations, including in North America, are expected to be announced throughout 2019.

IRAN

Natural gas production up 12%

According to the South Pars Gas Company, production of natural gas in the largest Iranian gas field increased by 12% in the year from March 2018 to March 19 (Iranian year 1397). Managing director Hadi Hashemzadeh Farhang told local media that the inauguration of two phases of the South Pars project during the year had pushed Iran ahead of Qatar in terms of gas extraction from the shared South Pars field (Qatar North Field). Gas extraction had risen by 7%, but the inauguration of gas processing plant expansions had taken actual sweet gas output up by 12%.

CANADA

Sulphur fuel conversion technology

Lloyds Register has provided independent verification for the hdyroconversion technology provided by Canadian oil technology company Genoil, which produces low sulphur fuel oil from high sulphur material and bypasses the need for full-blown refinery processing. Lloyds confirmed at a technology demonstration that a sample of ISO compliant fuel with a sulphur content of 1.7% was reduced to 0.38% sulphur.

David Lifschultz, CEO of Genoil, added: 'Gaining independent verification from a renowned shipping classification society of the product characteristics of the supplied sample at entry to the GHU process and the end product at completion of the process is a significant step for Genoil in proving to the industry that there is a less expensive means of ensuing compliance with 2020 regulations that doesn't require paying a large premium for distillate fuels, or investing millions of dollars of capital, which may never see full payback, in scrubber technology or LNG.

The company is targeting bunker fuel producers in the run up to the IMO low sulphur fuel regulations in 2020. Genoil supplies its Genoil Hydroconversion Upgrade (GHU) processing units which can be attached to an existing refinery at a port where there is a ready point to supply ships. GHU is a fixed bed catalytic desulphurization technology, which the company says can achieve 96% pitch conversion and 95% desulphurisation with an operating cost of up to 75% less than rival technologies.

UNITED KINGDOM

ExxonMobil to expand Fawley refinery

ExxonMobil says that it has made a final investment decision to spend more than $1 billion expanding its Fawley refinery in the UK in what is the largest investment the company has made in the UK in nearly 30 years. The company says that it will increase production of ultra low sulphur diesel (ULSD) by 38,000 bbl/d. The upgrade project will include a diesel hydrotreater and associated hydrogen plant which Exxon says will help improve the refinery's overall energy efficiency. Detailed engineering and design is underway, with construction set to begin in late 2019, and start-up scheduled for 2021.

"ExxonMobil continues to invest in the Fawley refinery and chemical plant, Britain's largest integrated facility," said Bryan Milton, President of ExxonMobil Fuels and Lubricants Company. "This investment will make Fawley refinery the most efficient in the United Kingdom".

The company says the investment will help reduce the UK's reliance on foreign diesel, with more than half of supplies imported in 2017.

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MOROCCO

Contracts awarded for new acid plants

ACS Group, through its engineering subsidiary Intecsa Industrial, says that it has been awarded two new contracts in Morocco, worth a total of €255 million. The contracts have been awarded by OCP for the construction of two new 5,000 t/d sulphuric acid plants at OCP's vast Jorf Lasfar site. The scope of the works includes basic engineering, detailed engineering, equipment and material supply, construction and implementation of the plants. Completion of the work is estimated at 26 and 32 months respectively. Sulphuric acid will be used for the production of phosphate fertilizers and the energy generated by these plants will be used in the industrial site where they will be located.

Outotec also says that it has signed a contract with OCP Group for the delivery of a sulfuric acid plant for fertilizer production. The approximately €80 million order has been booked into Outotec's 2019 first quarter order intake. Outotec's delivery includes the engineering, procurement and construction of the plant, to be based on Outotec's sulphur burning system. The new acid plant will incorporate proprietary technologies such as the *HEROS* heat recovery system as well as a converter, absorption towers and an acid distribution system made of Edmeston SX stainless steel alloy.

"Outotec's sulfuric acid technology has proven to be one of the leading technologies for decades. We are honoured that OCP has selected our design for their new plant. With our leading technologies providing benefits such as safety, high reliability and enhanced heat recovery we are happy to help OCP reach their sustainability targets," says Kalle Härkki, head of Outotec's Metals, Energy & Water business.

DENMARK

Temasek buys 30% of Haldor Topsoe

Haldor Topsøe Holding AS and global investment company Temasek have signed an agreement for Temasek to buy a 30% stake in Haldor Topsoe AS, for an undisclosed sum. The transaction is expected to be completed by the end of the year. Haldor Topsøe Holding AS, which is 100% owned by the Topsøe family, will remain the long-term majority shareholder of Haldor Topsoe AS.

"We are extremely pleased to welcome Temasek as our new minority shareholder in Haldor Topsøe. 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 Topsøe, Chairman of the Board of Directors, Haldor Topsøe Holding A/S.

"Topsoe is in a strong market position after some years of consolidation and restructuring. Now, we are ready for growth, and following a successful closing of this deal I am convinced that the collaboration between Topsoe and Temasek will be extremely beneficial for both parties," says Bjerne S. Clausen, CEO, Haldor Topsoe.

FRANCE

Axens to license ExxonMobil acid alkylation technology

Axens has signed an agreement with ExxonMobil Catalysts and Licensing to sublicense the latter's sulphuric acid alkylation technology. Under the agreement, both companies will market and distribute all technologies for high-octane gasoline production. The technologies to be accessible under the agreement include Axens feed preparation, or 'alkyfining', n-butane isomerisation and ExxonMobil's sulphuric acid alkylation, which reacts propylene, butylene and pentylene with isobutane to form high-value alkylate for gasoline blending. Axens will offer the technologies under a single licence and engineering agreement.

Axens chairman and CEO Jean Sentenac said: "We are excited by this agreement offering integration of advanced technologies to better meet refiners' needs for the production of alkylate, a key component of high-octane gasoline."

UNITED STATES

ioneer awards acid plant design contract

ioneer Ltd has awarded SNC Lavalin the engineering and design contract for a new sulphuric acid plant as part of the definitive feasibility study for the company's Rhyolite Ridge lithium boron project in Nevada. The 3,500 t/d acid plant will be used for leaching operations to produce lithium carbonate and boric acid. The acid plant will also produce the 50 MW of steam/heat necessary for the processing plant and export 'green energy' to the local grid. ioneer says that SNC has provided an updated budgetary cost estimate of about $111 million for the acid plant, $60 million lower than the estimate in the preliminary feasibility study (PFS) in October 2018.

ioneer's managing director Bernard Rowe said: "SNC-Lavalin is a longstanding leader in the sulphuric acid industry, they have a strong track record working with industry leading MECS technology from DuPont Clean Technologies. We are very pleased SNC-Lavalin and Du Pont will be joining us and our project lead engineers, Fluor, to further strengthen our world class team that is focused on progressing the DFS for the Rhyolite Ridge Lithium-Boron project, and to delivering an on budget and on-schedule project. The cost of the sulphuric acid plant is a key capex driver for the Rhyolite Ridge Project and the saving of approximately $60 million is significant and materially improves the already robust project economics demonstrated through the PFS."

At full capacity the Rhyolite Ridge mine will produce 20,000 t/a of lithium carbonate and ioneer's goal is to be in production by mid-2021.

IHP becomes Novaphos

JDCPhosphate says that it is moving to commercialisation of its Improved Hard Process (IHP) for phosphate production, and changing the name of the process to *Novaphos*. As part of the commercialisation process, JDC has inaugurated a new wholly owned subsidiary, Novaphos Inc. Novaphos produces high-quality super-phosphoric acid (SPA) from low-quality phosphate rock including mine tailings via a thermal process without creating problematic phosphogypsum waste. Instead, the process co-produces a commercially useful aggregate for construction and road building called *J-Rox*, which are the solid balls that remain after phosphate has been extracted during processing. Novaphos Inc has also announced that it has made additional process improvements which further enhance the efficiency and reliability of the technology, and says that it can now achieve phosphate yields of 80%. Acid quality also continues to improve, with impurities at about 2% of SPA-equivalent acid with strong potential for further improvement at commercial scale.

Novaphos continues to run its demonstration plant using only low-quality phosphate rock tailings, containing an average of about 14% phosphate as P_2O_5, with high levels of silica and other impurities, including magnesium oxide.

"The latest improvements to the Novaphos technology are very significant," said Ron Cambre, Novaphos board member and former CEO of Newmont Mining. "Based on my long career in mineral processing, including phosphates, I am excited to see the technology poised to start addressing the fundamental needs of the phosphate sector while minimizing toxic waste."

"Our new name is intended to signify Novaphos' readiness to move into the next phase of its business," said Timothy Cotton, CEO of Novaphos. "We will work with industry partners to commercialise our technology for making phosphate products that are vital to global food production."

IPNI closes its doors

The International Plant Nutrition Institute officially closed on April 1st, 2019. Based in Atlanta, Georgia, IPNI was founded in 2007 by producers of the major plant nutrients (nitrogen, phosphorus, potassium and sulphur) to conduct research on plant nutrition and agronomics, best practices and nutrient stewardship across the globe, with active programmes in Africa, Australia/New Zealand, Brazil, China, Eastern Europe/Central Asia and the Middle East, Latin America, North America and South and Southeast Asia. Member companies included Yara, CF Industries, PhosAgro, Nutrien, Mosaic, OCP, Simplot and Shell Sulphur Solutions.

At the behest of the members, the work of the organisation has now been transferred to three other associate member organisations; The Fertilizer Institute (TFI), Fertilizer Canada and the International Fertilizer Association (IFA). In a previous statement the three institutions thanked IPNI president Terry Roberts and his team for their "accomplishments and dedication… over many years."

First copper from Florence leach site

Canadian mining company Taseko Mines has announced that the company's Florence copper leaching project in Arizona is now fully operational and is producing copper. Over the first three months of the year 1.5 million tonnes of copper ore has been contacted with copper leach solutions, and concentrations in the solution have now risen to levels that have allowed the solvent extraction and electrowinning (SX/EW) plant to begin operations.

"The scale up from our laboratory and feasibility testing to the commercial scale has been relatively seamless. With the entire test wellfield and SX/EW plant now operating as a continuous unit, we will use the coming months to refine operational parameters, which will help with the ramp-up of the commercial plant," said president and CEO Russell Hallbauer.

Florence will produce an average of 38,700 t/a of copper for 20 years at an average operating cost of $1.10/lb.

RUSSIA

New acid plant for PhosAgro

PhosAgro has launched a project to build a new phosphate fertilizer facility and power plant at its Metachem production site at Volkhov near St Petersburg. The project includes the construction of a sulphuric acid production unit with a capacity of 800,000 t/a, a DAP production line, liquid ammonia storage, a finished product storage warehouse, a 25 MW heat energy generation unit and an overhaul of the phosphoric acid production unit, which will increase output capacity to 500,000 t/a.

PhosAgro CEO Andrei Guryev said: "this project is one of the key elements of PhosAgro's strategy to 2025. In essence, this is an entire new factory that will increase PhosAgro's total phosphate rock processing capacity by 1.0 million tonnes per year as well as increasing the production of higher margin phosphate-based fertilizers. The company says that integration of the fertilizer production facility with a 25 MW power plant, which uses high-tech water vapour generation, will significantly reduce the specific energy consumption per tonne of product. The total investment cost of the project is estimated at $360 million. The project is due to be completed by 2023.

Nornickel revises Sulphur Project cost estimate

Norilsk Nickel says that its Sulphur Project, aimed at cutting sulphur dioxide emissions from its Nornickel copper plant and Nadezhda Metallurgical Plant (NMP) at Norilsk, will now cost 150 billion rubles ($2.3 billion), an increase on the previous 123 billion ruble estimate ($1.9 billion). The project will collect 75% of SO_2 emissions from the metallurgical complex, removing 1.5-1.7 million t/a of the gas once it is fully on-stream by 2023. Polluting production at the copper plant will be shut down and blister copper production will be moved outside Norilsk city limits to the NMP. The installation of continuous converting facilities at the NMP will then capture large volumes of sulphur dioxide-rich emissions. The Sulphur Project will finally be completed once a recovery plant has been built at the NMP, where captured sulphur dioxide will be turned into sulphuric acid and neutralised by limestone to produce gypsum. There will also be an increase in elemental sulphur production. Overall production will be 280,000 t/a of sulphur and 5 million t/a of gypsum.

PHOTO: PHOSAGRO

Phosphate-potash production line at Metachem's Volkov site.

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BCInsight
Southbank House, Black Prince Road
London SE1 7SJ, England
Tel: +44 (0)20 7793 2567
Fax: +44 (0)20 7793 2577
Web: www.bcinsight.com
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PHOTO: CODELCO

Codelco's Chuquicamata open pit mine, the largest copper mine in the world.

CHILE

Codelco ends contract with SNC-Lavalin

Chilean state miner Codelco said on Monday it had terminated its contract with Canadian company SNC-Lavalin Group Inc at its Chuquicamata mine in northern Chile, accusing the engineering firm of failing to comply with its work commitments at the world's largest open pit mine. Codelco says that SNC-Lavalin failed to meet its commitments under a $260 million contract including quality issues and delays in subcontractor payments and project execution in the engineering, supply and construction of two 2,050 t/d MECS-designed sulphuric acid plants. The Chuquicamata upgrade and expansion has been a controversial one in Chile, with mass protests, rising costs and technical issues. SNC Lavalin has said in public statements that the challenges on the project are mainly due to unexpected site conditions, environmental and safety measures, as well as underperformance from sub-contractors. It described itself as "appalled and surprised" by the Codelco decision, which was "unwarranted and in breach of good faith agreements reached by the parties", especially with the project so close to completion, and the company said it was considering legal action to recover an estimated C$350 million in losses.

Chuquicamata is reported by Codelco to be 75% complete. The project is part of a ten year upgrade plan for the company's resources which will cost a total of $39 billion.

In a recent results presentation, Codelco, which produces 10% of the world's copper, said that in 2018 it produced 1.68 million t/a of copper at its own mines in 2018, down 3.3%t from the previous year, and a total of 1.81 million tonnes from jointly owned production, such as El Abra and Anglo American South. The company blamed ageing mines and declining ore grades on the decrease. Pre-tax profits for 2018 were $ 2.0 billion, down from $2.89 billion the previous year, mainly due to the decline in the price of copper. There was also a one-off write down of $400 million for deteriorating assets.

AUSTRALIA

Incitec Pivot to close SSP plant

Incitec Pivot has said that it will close its Portland, Victoria, single superphosphate (SSP) plant in May, following a strategic review. Operations will be consolidated to the Geelong, Victoria SSP facility, around 300 km to the east, but the Portland distribution centre will continue to operate as normal. Portland produces 180,000 t/a of SSP at capacity, while Geelong's output can reach 350,000 t/a. A strategic review was initiated in 2014 to optimise the SSP assets, with the product facing overcapacity and competitively priced imports.

Sulphuric acid and phosphate rock are imported to Portland and Geelong, with demand for both to decline as a result of the Portland closure. Phosphate rock is imported from international suppliers, while sulphuric acid is sourced domestically from mining and metals firm Nyrstar's zinc smelter in Tasmania.

King River revises acid plant cost estimates

King River Resources has provided a pre-feasibility study update on the company's Speewah Specialty Metals project in Western Australia's East Kimberley region. In the update, the company has estimated capital expenditure of A$359 million for its processing facility and A$580 million for its acid contact and regeneration plants. The project aims to produce vanadium, titanium and iron oxides, and comprises a beneficiation circuit, agitated tank leach circuit, and metal recovery circuit. The sulphuric acid plant will provide acid for leaching as well as steam and electricity to drive the entire process.

INDONESIA

Nickel leaching facility awaiting environmental clearance

Work has begun on a new nickel high pressure acid leaching (HPAL) plant at the PT Indonesia Morowali Industrial Park (IMIP) on Sulawesi. Ground was broken in January by project partners Tsingshan Group and battery manufacturer GEM Co Ltd, who are aiming to complete work in an ambitious 16-18 months. The plant aims to produce 130,000 t/a of battery grade nickel sulphate, as well as 13,000 t/a of cobalt sulphate and 27,000 t/a of manganese sulphate. Tsingshan is a major Chinese nickel miner who has revolutionised the nickel market via its nickel pig iron (NPI) production for stainless steel production. However, this is its first venture into HPAL production, and the aim of getting the plant on-stream by 2020 seems to fly in the face of previous HPAL project experience. Reuters has reported that the plant has still not yet received environmental clearnance to operate, and that it is still preparing its environmental impact assessment, which could take another 8 months to be approved.

INDIA

Vedanta smelter case drags on

There is still no sign of any re-start of Vedanta's Sterlite Copper Smelter plant at Thoothukundi in Tamil Nadu. The plant has been closed since April last year following disputes over emissions which led to public protests spiralling into fatal clashes with police which left 13 people dead. The Indian Supreme Court has passed the matter back to the Madras High Court, and overturned a ruling by the National Green Tribunal to restart the plant, which had in turn been closed by a decision of the Tamil Nadu Pollution Control Board. The Madras High Court has adjourned the case until April 23rd, and in the meantime has refused to issue an order on Vedanta Group's plea seeking an interim relief for care and maintenance of plant, which would have allowed the company to make perform necessary maintenance work to prevent deterioration of the plant.

Vedanta is also facing issues with a case in Zambia, where the UK Supreme Court ruled in early April that a case against the company in Zambia could be heard in the UK, where the company is based. More than 1,800 people allege that sulphuric acid contaminated waste from Vedanta subsidiary Konkola Copper Mines (KCM) has damaged land, waterways and impacted upon their health, and are suing for compensation. Vedanta commented: "The judgment of the UK Supreme Court is a procedural one and relates only to the jurisdiction of the English court to hear these claims. It is not a judgment on the merits of the claims. Vedanta and KCM will defend themselves against any such claims at the appropriate time."

JAPAN

Sumitomo smelter output to fall in 2019-20

Sumitomo Metal Mining Co., Ltd has outlined its production guidance for 2019 and 2020. The company says that it will produce 420,000 t/a of copper in 2019, down 0.8% from 2018. There is a 35 day maintenance stoppage scheduled for the Toyo Smelter and Refinery in October which will impact upon copper production. The year's electrolytic nickel production is expected to reach 62,600 t/a, down 3.5% on the previous year, but ferronickel production will be up 900 t/a to 13,330 t/a in 2019.

Guidance for the financial year to April 2020 indicates that copper production would be down 7.7% on the previous financial year.

BELGIUM

Trafigura to take over Nyrstar

Swiss-headquartered Trafigura Group says that it has entered into an agreement and committed to $348 million of funding as part of a deal to become majority owner of Belgian metals and mining company Nyrstar. Trafigura is also entering into a restructuring deal with Nyrstar's financiers over the company's debts. The move will reportedly not impact upon Nyrstar's Port Pirie smelter in Australia, which has an A$291 million state-guaranteed loan which Nyrstar is paying back. Prior to the purchase, Trafigura, which is worth $75 billion total assets, had been Nyrstar's largest single shareholder, with 24.42% of the company's shares.

TURKEY

Ground broken on new acid plant

A ground breaking ceremony has been held at the Eti Mine in the Emet district of Kütahya in Turkey for the construction of a new sulphuric acid production facility of Eti Mine in Emet district of Kütahya. The state-run Eti Mine is part of Turkey's huge boron reserves, and produces 50% of the world's borates. The ceremony was held under the auspices of Minister of Energy and Natural Resources Fatih Dönmez. The new facility will cost $75 million. The site has an existing 750 t/d acid plant of MECS design, completed in 2004.

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Southbank House, Black Prince Road
London SE1 7SJ, England
Tel: +44 (0)20 7793 2567
Fax: +44 (0)20 7793 2577
Web: www.bcinsight.com
www.bcinsightsearch.com

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People

Royal Dutch Shell has announced that its affiliates formerly operating under the CRI, Criterion and Shell Global Solutions tradenames will now operate under the new tradename of Shell Catalysts & Technologies for the delivery of catalyst, licensing and technical services for all of its customers worldwide. Together these companies will provide the energy and petrochemical industries with integrated and simpler interfaces, to take advantage of the superior offerings and services delivered across the businesses' portfolios.

"By combining our innovative products, services and people into the rebranded Shell Catalysts & Technologies, we will continue to power progress together to provide more and cleaner energy solutions in a more efficient way," said **Andy Gosse**, who becomes the new president of Shell Catalysts & Technologies. "We will continue to work closely with our customers to assess their specific needs and to support their overall business goals."

Vedanta has appointed metals industry veteran **Pankaj Kumar** as the chief executive of Sterlite Copper in India, following protracted legal struggles for the company to re-open its Sterlite Copper Smelter in southern India, shut in April 2018 following public protests which resulted in 13 deaths at the hands of local police. Kumar replaces **P Ramnath**, who led Sterlite for eight years. Under Ramnath, the smelter was ordered shut at least twice, including for an alleged gas leak in 2013.

"My tenure as the CEO has been an eventful journey, and as is the case with any journey, there have been numerous ups and downs," Ramnath, who will continue as an advisor to the company, said in a statement. Kumar, who will also oversee operations at Vedanta's Malco Energy Limited and Fujairah Gold, has worked at Hindustan Zinc , Tata Steel and Adani Ports, in a career stretching over 29 years. Kumar was also chief operating officer at Sterlite Copper in the past, the company said.

"It is an honour to be back in a place that feels like home," he said.

Metals and fertilizer consultancy CRU Group has announced the appointment of **David Trafford** as chief executive officer. 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. With his experience in transformational strategy and corporate development, David's leadership has established CRU Consulting as a world leader in providing informed and practical advice to meet the needs of customers and their stakeholders.

David Trafford.

Executive chairman of CRU Robert Perlman said: "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."

David Trafford commented: "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 loyal customers."

Calendar 2019

JUNE

7-8

AIChE Clearwater Convention,
CLEARWATER, Florida, USA
Contact: Ashley Rubright,
AIChE Central Florida Section
Email: vicechair@aiche-cf.org
Web: www.aiche-cf.org

11-13

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

JULY

15

Brimstone Amine Treating and SWS Course,
HOUSTON, Texas, USA
Contact: Mike Anderson, Brimstone STS
Tel: +1 909 597 3249
Email: mike.anderson@brimstone-sts.com

SEPTEMBER

16-20

Brimstone Sulphur Symposium,
VAIL, Colorado, USA
Contact: Mike Anderson, Brimstone STS
Tel: +1 909 597 3249
Email: mike.anderson@brimstone-sts.com

OCTOBER

7

Brimstone Sulphur Recovery Fundamentals Course, HOUSTON, Texas, USA
Contact: Mike Anderson, Brimstone STS
Tel: +1 909 597 3249
Email: mike.anderson@brimstone-sts.com

7-10

Middle East Sulphur Plant Operators Network (MESPON), ABU DHABI, UAE
Contact: UniverSUL Consulting,
PO Box 109760, Abu Dhabi, UAE.
Tel: +971 2 645 0141
Fax: +971 2 645 0142
Email: info@universulphur.com

NOVEMBER

4-7

European Refining Technology Conference (ERTC), WARSAW, Poland
Contact: Sandil Sanmugam, Conference Manager, World Refining Association
Tel: +44 20 7384 7744
Email: sandil.sanmugam@wraconferences.com

4-7

CRU Sulphur and Sulphuric Acid 2019 Conference, HOUSTON, Texas, USA
Contact: CRU Events
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

FEBRUARY 2020

Date T.B.A.

Laurance Reid Annual Gas Conditioning Conference, NORMAN, Oklahoma, USA
Contact: Tamara Powell, Program Director
Tel: +1 405-325-2891
Email: tsutteer@ou.edu

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BCInsight
Southbank House, Black Prince Road
London SE1 7SJ, England
Tel: +44 (0)20 7793 2567
Fax: +44 (0)20 7793 2577
Web: www.bcinsight.com
www.bcinsightsearch.com

China's phosphate industry

China is the largest producer and consumer of phosphates in the world, driving the country's massive consumption of sulphur and sulphuric acid. However, new governmental regulations on the environment are forcing the closure of smaller, less efficient and more polluting capacity and pushing up production costs.

China's phosphate industry saw remarkable growth from 2000-2015, turning the country into the largest producer and consumer of phosphates in the world. However, since that rapid period of development, growth has slowed and stagnated, leading to overcapacity both domestically and internationally. China's phosphate industry has soaked up most of China's sulphuric acid production over that period, and led to China being the largest importer of sulphur in the world. However, as phosphate production falls and the country engages in a large-scale environmental crackdown, at the same time that new smelter acid production and new domestic sulphur production reduce the demand for imports, it seems China is turning again.

Phosphate demand

Agriculture remains a topic of key concern to the Chinese government. The country's 'one child' policy slowed population growth during the late 1990s and most of the 21st century, but China's population has nevertheless reached 1.4 billion. Although the country is large in extent – roughly equivalent in size to the continental United States – much of it is desert or mountainous, especially the west and southwest, and the actual cultivated area is just 12% of China's land mass. The means that China's agriculture has had to become highly intensive in order to feed its people, as each hectare of arable land must feed twice the global average. China's agricultural production has been achieved via large application of fertilizer. China applied 500kg per hectare of fertilizer in 2016, around three times the average in the European Union, and in fact applied 30% of the world's artificial fertilizer that year. China uses 40% of its fertilisers on cereal crops, while another 33% is used for fruits and vegetables. Policy, via a system of price caps and subsidies, has been successful in producing enough food for China's needs, but as a result of over-application of fertilizer, nutrient leaching into water courses has become a major environmental issue for China, and over the past few years the government has tried to move towards a more efficient use of nutrients. This has included trying to balance the N:P:K application ratio (which had become skewed towards nitrogen – especially urea – application), and greater use of NPK blends and controlled and slow release fertilizers. The government also set a cap on overall fertilizer consumption from 2020 which is targeting nitrogen and phosphorus in particular, in order to encourage more balanced use of potassium and sulphur.

While China's consumption of phosphate fertilizers rose from 8.7 million tonnes P_2O_5 in 2000 to 14.4 million tonnes P_2O_5 in 2012, since then there has actually been a slow decline in phosphate applications, falling back towards 11.5 million tonnes P_2O_5 in 2017. IFA expects that over the next five years this will continue to see a slow decline, as more efficient fertilizer use and government caps on production and consumption continue to affect demand. One potential upside however is that China is looking to greater use of ethanol in fuel blending, attempting to follow the example of Brazil and the United States. The 13th Five Year Plan aims to double Chinese ethanol production from 2.4 million t/a in 2015 to 5 million t/a in 2020, while several provinces have adopted an E10 blending mandate, requiring fuel producers to mix 10% ethanol into their fuels. This means that China's ethanol consumption could actually rise to 15 million t/a, and this may lead to greater production of corn and other crops for ethanol production, requiring additional fertilizer inputs.

Phosphate production

China's phosphate production has increased rapidly to keep pace with the country's growing phosphate demand. Chinese diammonium phosphate production rose from 1.2 million tonnes P_2O_5 in 2002 to 8.1 million t/a in 2015, representing about half of global DAP production. At the same time, China's consumption of phosphate rock soared, and China consumed 49% of the world's phosphate rock in 2018. Set against Chinese DAP consumption of 4.4 million t/a P_2O_5 in 2015, this led to an increasing surplus – China was a net DAP importer until 2007, but since then has become an increasing large exporter to the world market.

Total phosphate fertilizer output in 2018 was 17.0 million tonnes P_2O_5. This included 7.5 million tonnes P_2O_5 of diammonium phosphate (16.2 million tonnes product) and 7.85 million t/a (P_2O_5) of monoammonium phosphate (15.1 million tonnes product). There was also a total of 36.7 million tonnes of NPK production (tonnes product) according to the China Phosphate and Compound Fertilizer Industry Association.

Most of China's phosphate fertilizer production is concentrated in five provinces: Hubei, Sichuan, Guizhou, Anhui and Yunnan, close to the country's phosphate rock resources in southern China. Hubei is the largest of these, representing approximately 34% of total output, followed by Yunnan and Guizhou with 24% and 15%, respectively (see Table 1). The five provinces together represent 85% of China's phosphate output.

The industry has some degree of concentration, with the top 10 producers collectively representing 63% of phosphate production according to the China Phosphate Fertilizer Industry Association (CFPIA). The five largest phosphate producers in 2018, according to CPFIA, were Yuntianhua, Guizhou Kaifeng Holdings, Yufu, Hubei Xinyangfeng, and Hubei Xiangyun.

Exports of DAP were even more concentrated, with the top five exporters representing 73% of the total of 7.47 million tonnes exported in 2018 (tonnes product). China also exported 2.49 million t/a of MAP (tonnes product) last year.

As Table 1 shows, the total output of phosphate fertilizer declined slightly in 2018 by just under 1%. Capacity, meanwhile stood at 23.5 million t/a (P_2O_5), for an overall utilisation rate of 73%. CPFIA estimates that 1.07 million t/a (P_2O_5) of phosphate capacity closed during 2018, and a further 880,000 t/a was idled. The industry continues to consolidate and close capacity in its attempt to improve competitiveness.

The 'New Era'

Part of this ongoing closure programme has been driven by environmental concerns. In October 2017 at the 19th National Congress of the Chinese Communist Party (CPC), 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 of 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 con-

Table 1: **Chinese phosphate fertilizer production, 2018**

Province	2018 production, million tonnes P_2O_5	Change vs 2017	% of total
Hubei	5.83	-1.0%	34.4
Yunnan	4.13	+5.7%	24.4
Guizhou	2.61	+3.9%	15.4
Sichuan	1.16	-0.7%	6.8
Anhui	0.78	-27.5%	4.7
Total	**16.96**	**-0.9%**	

Source: China Phosphate Fertilizer Industry Association

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Southbank House, Black Prince Road
London SE1 7SJ, England
Tel: +44 (0)20 7793 2567
Fax: +44 (0)20 7793 2577
Web: www.bcinsight.com
www.bcinsightsearch.com

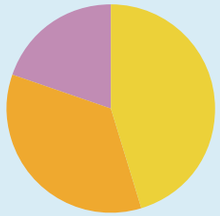
sumption and environmental protection are being imposed on newly built projects. High-pollution industries such as coking, tanning and electroplating are being strictly controlled, and companies with older and less efficient production capacity not in line with national industrial policy are forbidden 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.

China's phosphate industry is concentrated in the provinces along the Yangtze river; Sichuan, Guizhou, Hubei and Anhui; the Yangtze River basin accounts for nearly all of China's phosphate rock and about 90% of its finished phosphate production. Needless to say, phosphate production has been one of the industries targeted by the new environmental crackdown, especially in Hubei, where the river is a key conduit for raw materials and finished products. The provincial government has imposed a 1 km chemical production exclusion zone around the river and is forcing companies within it to relocate or shut down. Phosphate fertiliser manufacturers in the middle and upper reaches of the Yangtze River – the key source of phosphate ores – will be strictly banned from expanding capacity and will be required to relocate to industrial parks. Sichuan has forced some mines to close to protect nature reserves, while Hubei has especially gone after smaller, less efficient phosphate mines, with less than 150,000 t/a of capacity, closing some and increasing environmental scrutiny on the others. The Yichang City government has decreed all industrial activity in prohibited areas along the river must stop by the end of 2019.

Costs and production discipline

The net effect of these crackdowns has been to raise the cost of phosphate production. Some of this is purely due to raw materials shortages. The Chinese government expected that phosphate rock output would decline 30% in 2018 alone, for example, albeit much of this only on a temporary basis. There has also been a knock-on effect for ammonium phosphate producers from similar and parallel developments in China's nitrogen industry. 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.

Fig. 1: **Chinese sulphuric acid capacity, 2018**

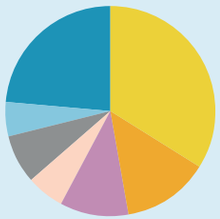


53.8 sulphur burning
41.5 smelter acid
23.3 pyrite roasting

Total: 122 million t/a

Source: China Sulphuric Acid Industry Association

Fig. 2: **Sources of Chinese sulphur, 2017**



5.8 Domestic recovered sulphur
2.3 Imported – Saudi Arabia
1.8 Imported – UAE
1.0 Imported – Qatar
1.3 Imported – Iran
0.9 Imported – Canada
4.0 Imported – Elsewhere

Total: 11.2 million tonnes

Source: TGO

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 phosphate industry. Cost competitiveness of Chinese phosphate capacity varies widely. This is especially relevant to the world market, as China is one of the largest exporters of phosphates and often the marginal producer and price setter. Some of the larger and better integrated producers are competitive in export markets, especially those with both rock mines and their own sulphuric acid and ammonia production, but others have found themselves more vulnerable, especially at a time, such as during 2016 and 2017, when overcapacity in global phosphate markets let to falling prices. During 2016 DAP prices fell below the cost of production for many Chinese producers. However, because of the relatively concentrated nature of the Chinese phosphate industry, some of the big producers were able to coordinate production cuts and running at reduced rates to 'spread the pain' and reduce the oversupply on global markets, bringing prices back up to a level at which they were competitive again.

Nevertheless, there have been closures. In 2015-17, about 1.8 million t/a of DAP capacity and 2.5 million t/a of MAP capacity was idled, according to Integer Research, most of it from smaller scale producers. Major producers have been able to commit significant funds to environmental remediation measures, but smaller scale producers have faced more difficulties and often received fines and other sanctions. Mosaic say that last year a team from their company visited the region and estimated about two-thirds of the 6.0 million t/a of DAP/MAP capacity in Yichang is at risk of closure by the end of 2019. Chinese MAP capacity in particular is towards the upper end of the cost curve and could be vulnerable to overseas competition. Most projections are currently for a slow, managed decline over the next few years, but new environmental initiatives could speed the pace of closures.

Meanwhile, closures on the phosphate rock mining side may turn China into a net importer of phosphate rock from about 2023. CRU reported at the Phosphates 2019 conference a few weeks ago that Chinese phosphate rock production costs are expected to rise above the global average site cost by 2020.

Overseas developments

As a consequence of the seismic changes in the Chinese domestic phosphate industry, some Chinese companies have been looking overseas. China's widely touted 'Belt and Road' initiative has seen the country coordinate its already impressive foreign investment in recent years to focus strategically on areas like south Asia and Africa, and one of the fruits of this has been the development of Chinese-owned or co-owned fertilizer capacity in countries in the target regions. In September 2018, one of the largest developments was announced in the phosphate sector, with China to cooperate with Algeria in developing a $6 billion phosphate project. The project unites CITIC and Wengfu Group (collectively taking a 49% share) with Algerian state oil and gas producer Sonatrach and state fertilizer producer Semidal, who will own the 51% majority stake. It covers developments in four areas, including the eastern province of Tebessa, where there is an investment budget of $1.2 billion in new mining, the eastern province of Souk Ahras with an investment put at $2.2 billion, the northeastern province of Skikda, with $2.5 billion, and the northeastern port of Annaba, with $200 million for infrastructure development. First production from the new sites is due to start in 2022.

China's sulphur and acid industries

The future of China's phosphate industry will have a major impact on the country's sulphur and sulphuric acid industries. According to the China Sulphuric Acid Industry Association, China's total sulfuric acid production capacity was 122 million t/a in 2018, up 0.9% year-on-year. Figure 1 shows the distribution of this production between the three major means of production. Sulphur burning capacity was down slightly by 1.3% to 53.8 million t/a, while smelter acid capacity was up 3.8% to 41.5 million t/a. Pyrite-based acid capacity was unchanged at 23.3 million t/a. Actual output during 2018 was 96.9 million t/a, up 0.9% on 2017, with sulphur burning acid production down 0.9% to 44.3 million t/a and smelter acid production up 5.6% to 35.0 million t/a. Pyrite acid production was down 2.6% year on year to 16.5 million tonnes.

The consequence of China's declining phosphate industry is that less sulphuric acid will be required for that purpose. Although China's industrial requirements for acid continue to increase, falling phosphate production has so far outweighed this. In the meantime, the addition of steadily increasing volumes of smelter acid mean that there is less requirement for on purpose acid production. It is usually anticipated that this will weigh most heavily upon the pyrite roasting acid sector, and although that sector has remained remarkably resilient through previous years, due to iron credits which allow it to break even, much of China's pyrite mining and roasting is also along the Yangtse River valley, and is also being squeezed environmentally, and may be forced to close preferentially.

Sulphur-burning acid capacity is also likely to feel the pinch, mainly where that is associated with closing MAP/DAP production capacity. This, and China's increasing domestic sulphur production from new refineries and sour gas expansions in the south of the country, argue for a slow decline in China's sulphur imports in the coming years.

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BCInsight

Southbank House, Black Prince Road
London SE1 7SJ, England
Tel: +44 (0)20 7793 2567
Fax: +44 (0)20 7793 2577
Web: www.bcinsight.com
www.bcinsightsearch.com

PHOTO: PETROBRAS

Focus on Brazil: refining and phosphates

In spite of the political and economic turmoil of the past few years, Brazil continues to be a bright growth spot for phosphate fertilizer demand. However, the country's sulphur and sulphuric acid balance depends upon the completion of several refining and phosphate producing projects.

Above: Storage tanks at a Petrobras refinery.

Although it has been through a rough time politically of late, with the echoes of the huge Operation Car Wash corruption scandal still reverberating and leading to the election of controversial populist president Jair Bolsonaro in late 2018. The huge corruption scandal, which has seen the jailing of one former president, the impeachment and removal of a second, and now the arrest of a third, has been a seismic shock to Brazil's politics. Bolsonaro, meanwhile, has proved a divisive figure, with his popularity rapidly plummeting after the election, and Brazil's legislature gridlocked.

The economy has suffered too, entering Brazil's worst ever recession from 2014-2016, and recovering only slowly from this, burdened by massive pensions spending, a complex tax system, regulatory uncertainty, crumbling infrastructure and widespread inefficiency. Brazilian GDP grew by only 1.0% in 2017 and 1.1% in 2018. The forecast for 2019 is marginally better at 2.0%, with projections still being revised downwards. But in spite of this, the country remains the economic powerhouse of Latin America. Brazil represents about half of South America's 420 million people, and 80% of the region's GDP. It is a huge country, resource rich, and was of course once styled one of the so-called BRIC countries, along with China, India and Russia, that grew on the back of the early 21st century commodity boom.

Oil and gas

Commodities – oil, gas, agriculture and minerals – were to have been at the heart of Brazil's success, and no less so than its rapidly developing oil and gas reserves. Between 1995 and 2005, huge offshore discoveries tripled Brazil's proved oil reserves to 12 billion barrels, and another 3 billion barrels have been discovered since. Potential reserves have been estimated at up to 30-40 billion barrels in total. The so-called pre-salt layer off the Brazilian coast has been the largest conventional oil discovery this century. Unfortunately, exploiting these reserves have proved problematic, not least because the sheer scale of them was a tempting target for corrupt government officials, and Brazil's state oil company Petrobras consequently found itself at the centre of the Operation Car Wash investigations.

Since the scale of the problems became clear, successive governments took steps to try and rein in the huge company. Upstream, Brazil has been inviting more foreign participation, ending the Petrobras monopoly on the offshore pre-salt deposits via a law in 2016. Five bidding rounds were conducted during 2017, with blocks won by ExxonMobil, Shell, Repsol YPF, Chevron, Wintershall, BP and Statoil, in various combinations (some with Petrobras involvement). The total investments in these blocks could total $80 billion according to Petrobras, and include 5 platforms and hundreds of wells, with an additional 2 million bbl/d of production at capacity. Three more licensing rounds were concluded in 2018, and another three are planned for completion in 2019. In 2018, there were also changes to Brazil's rules regarding minimum percentages of locally-sourced goods and services required in exploration and production contracts, known collectively as the 'Local Content' rules –reducing mandatory Brazilian participation by half, which also allowed greater use of floating production, storage and offloading (FPSO) units – some 36 are planned to help develop an estimated 21 billion barrels of oil equivalent in stranded oil and gas resources out to 2027. Brazil's oil production was 2.7 million bbl/d by late 2018 (up from 2.0 million bbl/d in 2013), but the country hopes to lift this to 5.5 million bbl/d by 2028, most of this offshore, to counter falling onshore domestic oil production.

On the gas side, Brazil produces about two thirds of its 74 million m^3/d of requirements, with the rest coming either from pipeline via Bolivia (31%) and the remaining 3% from LNG imports. Brazil hopes to increase gas' share of electricity production, and aims to collect and use more offshore gas.

Refining

Sulphur production in Brazil comes almost exclusively from oil refining. Until comparatively recently Brazil was largely self-sufficient in refined products. However, stagnation in its refining throughput (in spite of some increases in notional capacity) at the same time that there has been a rapid increase in domestic demand has seen this slip into progressively greater imports. Currently Brazil imports 540,000 bbl/d of refined products, around 20% of its requirements. The country is the seventh largest consumer of refined products in the world. As Table 1 shows, Brazil has 17 refineries with a total capacity of 2.3 million bbl/d – just over one third of South America's 6.3 million bbl/d total. Brazil's refining sector is also almost unique in the extent of participation of sugar cane-based ethanol that is used as fuel on its own or in blends – up to 570,000 bbl/d of capacity. On top of this, there is also 140,000 bbl/d of biodiesel capacity in the country.

Table 1: **Brazil's refining industry**

Refinery	Location	Operator	Capacity, bbl/d
REPLAN Paulínia	Paulinia	Petrobras	415,000
RLAM	Sao Francisco do Conde	Petrobras	280,000
REVAP	Sao Jose dos Campos	Petrobras	251,500
REDUC	Duque de Caxias	Petrobras	242,000
REPAR	Araucaria	Petrobras	220,000
REFAP	Canoas	Petrobras	201,000
RPBC	Cubatao	Petrobras	170,000
REGAP	Betim	Petrobras	151,000
RNEST Phase 1	Pernambuco	Petrobras	115,000
Lubnor	Fortaleza	Petrobras	82,000
RECAP	Maua	Petrobras	53,500
REMAN	Manaus	Petrobras	46,000
RPCC	Guamare	Petrobras	35,000
Refinaria Ipiranga	Pelotas	Riograndense	17,000
Refinaria Manguinhos	Rio de Janeiro	Peixoto de Castro/Repsol YPF	13,800
Univen	Itupeva	Univen Petroleo	6,900
DAX Oil	Camacari	Dax-Oil	2,100
Total			**2,301,800**

Source: Petrobras

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London SE1 7SJ, England
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Fax: +44 (0)20 7793 2577
Web: www.bcinsight.com
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One thing that Table 1 makes very clear is that state monopoly Petrobras continues to have a stranglehold on refining, with 98% of Brazil's refining capacity. As with the upstream sector, however, the country is also looking to increase foreign and private participation in its refinery operations. In 2018 it announced that during 2019 Petrobras will offer 60% shares in four of its largest refineries in two blocks; RNEST and RLAM in the northeast, and REPAR and REFAP in the southwest, which have a total of 850,000 bbl/d of refining capacity between them. This will take Petrobras' overall share in Brazil's refining down to about 75%.

As Brazil's oil production continues to increase, the plan was to have refining capacity move in step with this. Petrobras has for many years had a very ambitious spending program, announcing and initiating plans for several large grassroots refinery projects. However, in spite of the money spent, only one has so far actually made it to start-up, Phase 1 of the Abreu e Lima refinery (RNEST) in the northwest of Brazil, and this has come with an eye-watering $16 billion price tag. The second phase, which will take the refinery to its total figure of 230,000 t/a, is still under construction. Other projects have been plagued by delays, cancellations and cost overruns, with corruption and poor management taking their toll. One of the worst offenders has been the 165,000 bbl/d COMPERJ grassroots refinery project outside Rio de Janeiro. This was originally proposed in 2004, with a cost estimate of $2.5 billion. Ground was broken in 2008, but construction on the project was halted in 2015 after a reported $14 billion had been spent on the project. Work on two other new Petrobras refineries, Premium I and II, with a combined capacity of 900,000 bbl/d, was also abandoned in 2015. With new refinery capacity coming on-stream only slowly, the net effect of Brazil's rising oil production is that the country became a net oil exporter in 2014, and its exports are continuing to rise; it is currently one of the largest non-OPEC exporters.

New refinery capacity

In spite of the various delays and setbacks, there is still new refining capacity on the horizon. The 115,000 bbl/d RNEST phase II project, possibly boosted by foreign ownership later this year, is now on course for completion in 2022. Meanwhile, in late 2018, China's CNPC came to the rescue of the troubled COMPERJ project, buying a 20% stake in it and some associated offshore oil fields. The project, which was reportedly 80% complete at the time it was abandoned, appears to now be back on again, and there is talk of completion in 2023, at an additional $2 billion in investment.

A company called Noxis Energy is reportedly also looking at four new small coastal refineries, each with a capacity of 25,000 bbl/d, at in São Mateus in Espiritu Santo state, Barra dos Coqueiros in Sergipe state, Bacabeira in Maranhão, and Santana in Amapa state. Noxis is budgeting $1.3 billion for the projects. Finally, there is talk that the Premium I refinery could be partially revised to a new smaller target size of 240,000 bbl/d, with technology coming from Chinese companies including Sinopec. Petrochemical Refinery Brazil has gained access to the Bacabeira site, where Chinese companies are also developing the port.

It is also hoped to assist refinery development by moving towards a more competitive domestic fuel environment, with reduced subsidies and price controls. However, the move to decontrol domestic fuel prices has led to greater volatility which in turn led to the truck drivers' strike of 2018, and this has put the government on the back foot somewhat. Outside of Brazil, Petrobras has been divesting. In January, its sold its Pasadena refinery in Texas to Chevron for $562 million, half of what it paid to acquire it in 2006; a purchase later investigated during Operation Car Wash.

Sulphur production

Brazil's crude oil is fairly low sulphur, and its refineries have not run at full operating rates – typically 80-85% of capacity rather than the 90-95% typical in North America. This has historically been because of a mismatch between refinery configurations and the domestic demand product mix, which is dominated by gasoline and diesel for transport use. Many of the refineries have also lagged well behind their North American counterparts in terms of upgrading and desulphurisation capacity. Laws permitted the use of gasoline with up to 1,000 ppm sulphur until as late as 2014, and the current standard of 50 ppm is still above much of the developed world. The net result of these factors is that Brazil's refineries produced only 280,000 tonnes of sulphur in 2017.

There was to have been more sulphur recovery from the new refineries which would have increased this total significantly. The abandoning of the Premium I and II refineries at Maranhao in 2015 has in effect removed 230,000 t/a of potential new sulphur production. The RNEST Phase 1 project, meanwhile, has instead included an emissions abatement unit which can process 650,000m³ of sulphur-rich process gas at capacity, generating up to 700 t/d of sulphuric acid from a Topsoe WSA unit.

Metallurgical acid

While domestic sulphur production is relatively modest, Brazil's sulphuric acid capacity is boosted by moderate volumes of acid from smelting – around 850,000 t/a, all of which is consumed domestically by the fertilizer industry. Together with refinery sulphur, this takes equivalent production of sulphur in all forms (SAF) to about 560,000 t/a.

The major copper smelter is Paranaparema, which has 285,000 t/a of copper production capacity via smelting and refining at its Dias D'ávila plant, producing up to 560,000 t/a of sulphuric acid. Votorantim Metais also has zinc/lead smelting capacity at Juiz de Fora, zinc smelting at Três Marias, and nickel smelting at Forteleza, with a total acid capacity of 460,000 t/a, although production generally runs lower than this. Finally, AngloGold Ashanti operates two complexes in Brazil, one of which, Cuiabá, processes ores from the Cuiabá and Lamego mines and also produces around 200,000 t/a of sulphuric acid as a by-product, which is sold commercially on the domestic market.

Sulphur demand – fertilizers

As one of the world's largest agricultural producers, Brazil is most notable to the sulphur industry as a source of demand, and most of this goes into fertilizer production. Agriculture and agribusiness represented 23.5% of Brazil's GDP in 2017, and although agricultural output fell by 1.6% in 2018, mainly as a result of the truckers' strike mentioned earlier, it is forecast to grow by 2% in 2019. Agricultural exports actually keep Brazil's balance of payments positive, as its industrial and service sectors are net importers in spite of its increasing oil exports. Brazil is the world's largest exporter of soybean, sugar, coffee, citrus fruit, cattle, poultry and ethanol and the second largest exporter of corn.

The fastest growing sector is soybean cultivation, which is rising by 5-6% year on year, from 40 million tonnes in 2001 to over 110 million tonnes in 2018. Brazil now produces one third of the world's soybeans. Most of this goes to China – China imported 88 million tonnes of soybeans in 2018, 75% of it from Brazil. However, poor soil quality requires significant nutrient application to achieve this productivity – much of the arable land brought into cultivation has been in the Cerrado region, a band of savannah in the west of Brazil across Mato Grosso, Mato Grosso do Sul and Goias states, and this has required additional inputs to convert it to productive agricultural pasture land. Brazilian fertilizer demand has risen by more than 5% year on year for the past two decades, faster than anywhere else in the world, rising from 24 million tonnes nutrient in 2007 to 34.4 million tonnes in 2017.

> **Brazilian fertilizer demand has risen by more than 5% year on year for the past two decades.**

Soybeans are phosphate intensive, and Brazil continues to be a bright spot for phosphate demand, with a forecast increase of 2.1% year on year for the foreseeable future. Phosphate demand rose from 3.7 million tonnes P_2O_5 in 2010 to 5.6 million tonnes P_2O_5 in 2017, and in spite of a slight fall in 2018, it is forecast to rise to 7.2 million tonnes P205 by 2022. Mosaic said in a recent forecast that it is anticipating this trend to continue, with Brazil's phosphate demand increasing 3.8% in 2018, 2.7% in 2019, and around 1.8% per year out to 2023.

Domestic production of phosphates is relatively small compared to Brazilian demand – Brazil Mosaic is one of the major producers following its 2017 acquisition of Vale Fertilizantes – the company operates five phosphate mines in Brazil, at Tapira, Catalao, Patos de Minas, Cajacti and Araxa. All apart from Tapira also have downstream finished phosphate production, and there is also a single superphosphate (SSP) and phosphate fertilizer plant at Alto Araguaia. Mosaic produces about 80% of Brazil's phosphate rock; 4.6 million tonnes according to Integer Fertilizers. However, Mosaic has recently idled production at its Tapira and Catalao phosphate mines in April 2019 after the Brazilian government introduced new rules on tailings dams. This followed the terrible tailings dam collapse at Vale's Brumadinho iron ore mine in January, which killed more than 300 people.

Mosaic's finished phosphate fertilizer capacity totals 2.2 million t/a of SSP, 900,000 t/a of MAP, 800,000 t/a of TSP and 500,000 t/a of di-calcium phosphate (DCP). As well as Mosaic's production, Copebras, now owned by China Molybdenum, has some phosphate rock mining and 1.1 million t/a of downstream phosphate production, including SSP, MAP and DCP. Yara bought Vale's Cubtatao site in May 2018, which includes 700,000 t/a of phosphate fertilizer production, and also has phosphate rock mines and three SSP production sites from its purchases of Bunge in 2013 and Galvani in 2014. Itafos also operates an SSP production site at Arraias, producing about 500,000 t/a.

Brazil mined 5.5 million tonnes of phosphate rock in 2017, or about 1.6 million tonnes P_2O_5. An additional 1.8 million tonnes of phosphate rock (0.6 million tonnes P_2O_5) was imported to feed domestic phosphate production, and in total Brazil produced 2.2 million tonnes P_2O_5 of phosphate fertilizer in 2017, mainly single superphosphate and mono-ammonium phosphate (MAP), with some diammonium phosphate (DAP), triple superphosphate (TSP) and other phosphates. However, with total phosphate demand running at 5.6 million tonnes P_2O_5, this meant that the country has to import large tonnages of processed phosphates in order to make up the shortfall, mainly MAP (2.1 million tonnes P_2O_5 in 2017), but also some DAP, TSP and nitrophosphates (NP). China, the USA, Morocco and Russia are among the main suppliers.

New demand

Considering Brazil's extensive reserves of phosphate rock and ongoing and increasing production shortfall, there are plans for more domestic processed phosphate production. China Molybdenum, which bought out some of Anglo-American's assets in 2016, is building more MAP and TSP capacity at its Catalao site, to a total of about 440,000 t/a P_2O_5. This is expected to be onstream in late 2020, although there have been concerns expressed by president Bolsonaro about Chinese investment in Brazil during the election campaign, and it remains to be seen how he will react now in office.

Yara also inherited an expansion project from Galvani at Serra do Salitre, mining 1.2 million t/a of phosphate rock and producing more than 1.0 million t/a of finished fertilizers, SSP, TSP, and including 350,000 t/a of MAP – total tonnage in terms of P_2O_5 is 155,000 t/a. Again this is targeted for 2020 start-up. There are also several other speculative projects that could add further tonnages in the medium term.

Sulphur balance

Brazilian sulphur demand was about 2.3 million t/a in 2017 to feed sulphur-burning acid capacity in the country, in spite of sulphuric acid production from metallurgical sources which is sold domestically. There is about 7 million t/a of sulphur burning sulphuric acid capacity in Brazil, split between the main fertilizer producers; mainly Mosaic (4.8 million t/a) and Copebras (1.2 million t/), but Itafos, Heringer and Yara also have smaller acid plants. New acid plants form part of the Serra do Salitre project, with about 900,000 t/a of acid capacity, and the Copebras/China Molybdenum expansion includes about abother 1.1 million t/a of acid production.

Set against current sulphur demand is sulphur production from refineries of 280,000 t/a. This leads to a shortfall of over 2 million t/a of sulphur, which Brazil imports, mostly from Russia and the US, although Abu Dhabi, Kazakhstan and Canada are also major suppliers. Sulphur imports rose from about 2.0 million t/a in 2018 to 2.3 million t/a in 2018.

The new phosphate projects will require up to another 650,000 t/a of sulphur once complete and running at capacity taking Brazilian imports to 3.0 million t/a from 2020-21. The RNEST II refinery meanwhile has another 230,000 t/a of sulphuric acid production attached, which could substitute for some of Brazil's sulphur requirement, but this is not projecting completion before 2023. Other refinery projects are either small or continue to be delayed. The likelihood, therefore is that Brazil's sulphur requirement will continue to rise over the next few years as new phosphate fertilizer projects are completed.

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Southbank House, Black Prince Road
London SE1 7SJ, England
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Web: www.bcinsight.com
www.bcinsightsearch.com

Sulphur recovery projects 2019

Sulphur's annual survey of recent current and future sulphur recovery unit construction projects maps the developing shape of brimstone production from fuel and gas processing plants worldwide.

PHOTO: KT KINETICS TECHNOLOGY

Sulphur recovery unit in Turkey.

Operating company	Operating site	Process type	Total new capacity	Licensor(s)	Lead contractor	Project type	Planned startup date
ALGERIA							
Sonatrach	Tiaret, Hassi Messaoud	Amine, SWS	770 t/d	Wood Group	Wood Group	New	n.a.
AZERBAIJAN							
SOCAR	Baku HAOR	Claus, TGT, amine, H_2S, CO_2	2 x 30 t/d	Tecnimont, UOP, Wood Group	Wood Group	New	2021
BAHRAIN							
Bapco	Sitra Refinery	Claus, NH_3, amine, SWS, AGRU	3 x 250 t/d	WorleyParsons	n.a.	New	2020
BELGIUM							
ExxonMobil	Antwerp Refinery	O_2 enrich, amine, TGT	325 t/d	WorleyParsons	Wood Group	Revamp	2018
BRAZIL							
Petrobras	Rio de Janeiro	SuperClaus	2 x 62 t/d	Jacobs	n.a.	Revamp	2018
Petrobras	Belo Horizonte	SuperClaus	2 x 62 t/d	Jacobs	n.a.	Revamp	2020
CAMEROON							
SoNaRa	Limbe	SRU, SWS	17 t/d	Wood Group	KT Kinetics Technology	New	2018
CANADA							
Pembina-Veresen	Hythe	SuperClaus	2 x 310 t/d	Jacobs	n.a.	New	2021
Pembina-Veresen	Two Lakes	SuperClaus	2 x 62 t/d	Jacobs	n.a.	Revamp	2020
PetroCanada	Fort Hills Upgrader	Claus, NH_3, amine	2 x 700 t/d	WorleyParsons	n.a.	New	On hold
CHINA							
Jiutai Energy	Linyi, Shangdong	EuroClaus	32 t/d	Jacobs	n.a.	New	2019
Sinopec	Fujian	SuperClaus	513 t/d	Jacobs	n.a.	New	2019
Shaanxi Yancheng	Yulin, Shaanxi	EuroClaus	41 t/d	Jacobs	n.a.	New	2019
COLOMBIA							
EcoPetrol	Barrancabermeja	Claus, NH_3, amine	2 x 130 t/d	WorleyParsons	n.a.	New	On hold
CROATIA							
INA	Rijeka	Claus	95 t/d	WorleyParsons	n.a.	New	2019
FRANCE							
Total	Donges	SWS	n.a.	Wood Group	Wood Group	New	2021
Total	Normandy	SuperClaus	96 t/d	Jacobs	n.a.	Revamp	2019
GREECE							
Hellenic Petroleum	Thessaloniki	Claus, TGT, degassing	n.a.	Siirtec Nigi	n.a.	New	n.a.
INDIA							
Essar Oil	Vadinar	Claus, SCOT	675 t/d	Jacobs	n.a.	New	2019
Reliance	Jamnagar	O_2, NH_3, amine, TGT	4 x 1,300 t/d	WorleyParsons	n.a.	New	2018
HPCL	Vishakhapatnam	Claus, SCOT	2 x 450 t/d	Jacobs	Petrofac	New	2022
IOCL	Panipat	Claus, TGT	225 t/d	PROSERNAT	n.a.	New	2020
IOCL	Mathura	Claus, TGT	2 x 425 t/d	PROSERNAT	n.a.	New	2020
IOCL	Bongaigon	Claus, TGT	20 t/d	PROSERNAT	n.a.	New	2020
IOCL	Bathinda	Claus, TGT	750 t/d	PROSERNAT	n.a.	New	
2019**INDONESIA**							
PT Medco E&P	East Aceh	EuroClaus	48 t/d	Jacobs	n.a.	New	2019
PT Pertamina	Cepu	Claus, SCOT	122 t/d	Jacobs	n.a.	New	2019
Pertamina	Balongan	Claus, NH_3, H_2, amine, TGT	1,100 t/d	Wood Group	n.a.	New	n.a.
IRAQ							
Turkish Pet Int	Mansuriyah	Claus, amine	230 t/d	WorleyParsons	n.a.	New	2019
ISRAEL							
Bazan	Haifa Refinery	O_2 enrich	3 x 100 t/d	WorleyParsons	n.a.	Revamp	2019
JAPAN							
JXTG	Mizushima	SuperClaus	2 x 175 t/d	Jacobs	n.a.	Revamp	2020
JORDAN							
JPRC	Zarqa	Claus, SCOT	2 x 250 t/d	Jacobs	n.a.	New	2021
KUWAIT							
Chevron	Wafra	Claus, amine	2 x 218 t/d	WorleyParsons	n.a.	New	2018
KNPC	Al Zour Refinery	Claus	1,500 t/d	Wood Group	Jacobs	New	2019
KOC	JPF	Claus, TFTU	2 x 100 t/d	Siirtec Nigi	Schlumberger	New	2018
KOC	JPF	SmartSulf	2 x 100 t/d	PROSERNAT	PROSERNAT	New	2018
KNPC	Mina al Ahmadi	Claus, amine, TGT	2 x 400 t/d	WorleyParsons	n.a.	New	2019
MALAYSIA							
MRC	Melaka	SuperClaus	220 t/d	Jacobs	n.a.	New	2021
Petronas	Johor	SuperClaus	3 x 470 t/d	Jacobs	n.a.	New	2019

KEY

BTX = BTX destruction
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PROCESS PLANT SURVEY

SULPHUR
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BCInsight

Southbank House, Black Prince Road
London SE1 7SJ, England
Tel: +44 (0)20 7793 2567
Fax: +44 (0)20 7793 2577
Web: www.bcinsight.com
www.bcinsightsearch.com

Operating company	Operating site	Process type	Total new capacity	Licensor(s)	Lead contractor	Project type	Planned startup date
MEXICO							
PEMEX	Minatitlan	SmartSulf, NH_3	2 x 50 t/d	WorleyParsons	n.a.	New	On hold
PEMEX	Cadareyta	SmartSulf, NH_3	132 t/d	WorleyParsons	n.a.	New	On hold
PEMEX	Tula, Hidalgo	EuroClaus	3 x 640 t/d	Jacobs	n.a.	New	2019
NETHERLANDS							
Total/Lukoil	Zeeland	SWS	n.a.	Wood Group	Wood Group	Revamp	2020
NIGERIA							
Dangote Oil	Lekki Refinery	SuperClaus	2 x 115 t/d	Jacobs	n.a.	New	2019
OMAN							
OOC	Duqm Refinery	Claus, H_2, SWS, amine	3 x 355 t/d	Jacobs	Tecnicas Reunidas	New	2021
PERU							
Repsol	La Pampilla	2 x Claus, NH_3, O_2, H_2, amine, TGT	37 t/d	Wood Group	n.a.	New	n.a.
QATAR							
Qatar Petroleum	Mesaieed	AGE, Claus, TGT	310 t/d	Worley Parsons	n.a.	Revamp	2019
RUSSIA							
Bashneft	Ufa	Amine, SWS	n.a.	Wood Group	n.a.	New	2023
Bashneft	Ufa	SmartSulf	115 t/d	PROSERNAT	n.a.	New	2018
Gazpromneft	Moscow	LPG treat, amine	n.a.	Wood Group	Wood Group	New	2019
Lukoil	Volgograd	NH_3, H_2, amine, TGT, D'GAASS	2 x 76 t/d	Fluor	n.a.	New	2018
Rosneft	Novokuibyshev	Claus, NH_3, amine	2 x 192 t/d	WorleyParsons	n.a.	New	2019
Rosneft	Saratov	EuroClaus	283 t/d	Jacobs	UOP	New	2020
Orsknefteorg	Orsk	EuroClaus	2 x 99 t/d	Jacobs	n.a.	New	2019
Taneco	Nizhnekamsk	Claus, TGT	3 x 410 t/d	WorleyParsons	n.a.	Revamp	2019
SAUDI ARABIA							
PetroRabigh	Rabigh	EuroClaus	292 t/d	Jacobs	n.a.	New	2019
Saudi Aramco	Tanajib Gas Plant	Claus, O_2 enrich, amine	3 x 1,000 t/d	WorleyParsons	n.a.	New	2020
Saudi Aramco	Jafurah Gas Plant	Claus, O_2 enrich, amine	3 x 350 t/d	WorleyParsons	n.a.	New	2021
SERBIA							
NIS	Pancevo Refinery	Claus, NH_3, amine	170 t/d	WorleyParsons	n.a.	Revamp	2019
SINGAPORE							
SRC	Jurong Island	Claus, O_2 enrich, NH_3	145 t/d	WorleyParsons	n.a.	Revamp	On hold
SRC	Jurong Island	SuperClaus	2 x 65 t/d	Jacobs	n.a.	Revamp	2019
ExxonMobil	Pulau Ayer	SuperClaus	400 t/d	Jacobs	n.a.	New	2020
SOUTH AFRICA							
Chevron	Cape Town	Claus, SCOT	2 x 45 t/d	Jacobs	Fluor	Revamp	2019-20
SOUTH KOREA							
Hyundai	Daesan	O_2 enrich	410 t/d	WorleyParsons	n.a.	Revamp	2019
S-Oil	Onson	Claus, amine, TGT, SWS	2 x 220 t/d	Wood Group	Wood Group	New	2018
SPAIN							
Cepsa	Algeciras	Claus, SCOT	280 t/d	Jacobs	n.a.	New	2019
BP Oil	Castellon	EuroClaus	2 x 45 t/d	Jacobs	n.a.	Revamp	2018
THAILAND							
Thai Oil	Sriracha Refinery	Claus, NH_3, Flexsorb	2 x 837 t/d	WorleyParsons	Wood Group	New	2021
TURKEY							
STRAS	Aliaga/Izmir	SRU, TGT, amine, SWS	463 t/d	Tecnimont KTI	Wood Group	New	2018
Tupras	Izmir	Degassing	240 t/d	Jacobs	n.a.	New	2020
Tupras	Izmit	EuroClaus	240 t/d	Jacobs	n.a.	New	2020
Tupras	Kirikale	EuroClaus	135 t/d	Jacobs	n.a.	New	2020
TURKMENISTAN							
Turkmenbashi Oil	Turkmenbashi City	SuperClaus	25 t/d	Jacobs	Hyundai	New	Delayed
UNITED ARAB EMIRATES							
Al Hosn Gas	Shah	n.a.	4 x 1,250 t/d	n.a.	Wood Group	Revamp	2022
Takreer	Ruwais	n.a.	n.a.	n.a.	Wison Engineering	Revamp	2021
UNITED STATES							
Chevron	Richmond, CA	O_2 enrich	580 t/d	WorleyParsons	n.a.	Revamp	2018
UNITED KINGDOM							
Eni	Point of Ayr	Claus, amine, TGT	n.a.	WorleyParsons	n.a.	Revamp	2019
UZBEKISTAN							
Lukoil	Kandym	SuperClaus, TGT	2 x 405 t/d	Jacobs	n.a.	New	2018
Mubarek	Mubarek Gas Plant	Claus, amine	1,000 t/d	WorleyParsons	n.a.	New	2020
VENEZUELA							
PDVSA	El Palito	SRU, amine, TGTU, SWS	250 t/d	Shell	Wood Group	New	2018
PDVSA	Puerto La Cruz	Claus, NH_3, amine	2 x 225 t/d	WorleyParsons	n.a.	New	2019
VIETNAM							
Bin Son Refinery	Dung Quat	Claus, SCOT, TGT, SWS	2 x 105 t/d	Jacobs, Amec Foster	Wood Group	New	2019

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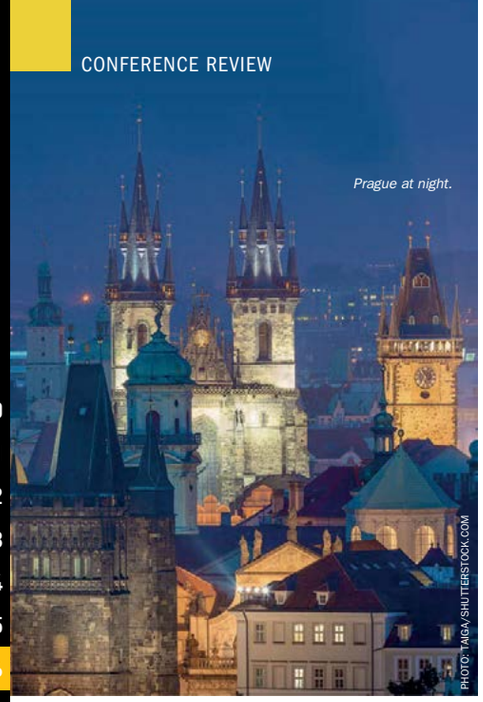

Prague at night.

PHOTO: TAGA/SHUTTERSTOCK.COM

TSI World Sulphur Symposium 2019

The impact of the upcoming IMO regulations on sulphur content of shipping fuels and China's changing phosphate, sulphur and sulphuric acid mix were among the topics discussed at this year's meeting.

The Sulphur Institute's annual World Sulphur Symposium was held in Prague this year, and brought together 125 sulphur and sulphuric acid business delegates for three days of discussion of the state of the industry.

Central Asian Summit

On the Monday preceding the conference, there was a short afternoon session dedicated to the sulphur situation in Central Asia. TSI's Craig Jorgensen began with an overview of the region and its countries and the logistical hurdles in getting sulphur out of the region, with major ports 2-3,000 km away in the Baltic or Black Sea, and long overland routes to China.

Sulphur editor Richard Hands discussed the oil and gas industry of the region and the major sour gas and oil projects which produce sulphur. With Kashagan now up and running, and likewise Kandym in Uzbekistan, there are no major sour gas projects on the horizon in the medium term, and most new oil and gas projects are either sweet or involve sour gas reinjection.

Jerry D'Aquin suggested that the move of the sulphur industry from North America to places such as Central Asia and the Arabian Gulf means that a great deal of expertise in sulphur handling, health and safety has not been passed on, and so discussed the potential hazards of sulphur forming, handling and shipping, particularly fire and explosion due to sulphur particulate dust.

Finally, Meena Chauhan of Argus Media described the sulphur and sulphuric acid markets of the region. Central Asia is a major net exporter – Russia and Kazakhstan between them exported 6 million t/a of sulphur in 2018. Regional production is set to rise by another 1 million t/a over the next few years. However, the logistical difficulties of the region mean that in countries like Turkmenistan and Uzbekistan new production is increasingly being stockpiled. Russia offers the greatest prospect for new demand as the country's phosphate fertilizer industry develops.

Economic outlook

Gabriel Stein of Stein Brothers forecast below average growth for the global economy in 2019, as evidenced by a negative move in the 'broad money' supply and share prices in all major economies of the world during 2018 as compared to 2017. There are a number of factors bearing on this, including central banks 'normalising' interest rates after a period of 'quantitative easing', concerns over how long this period of expansion will last, the effects of Brexit and the US-China trade dispute, and of populist politics more generally.

Global energy outlook

Looking to the longer term, Francis Osborne of Arugs told delegates that "decarbonisation [of energy] is here to stay" and becoming mainstream policy. A number of countries are looking to end the production and sale of internal combustion vehicles over the next couple of decades, with Germany and the Netherlands targeting 2030, Norway 2025 and the UK, France and China 2040. Around 10% of all new vehicles will be electric by 2030, and perhaps 25% by 2035, he said. However, in the short to medium term the remains no alternative to oil, and oil demand growth is expected to rise by 12% to 2025, possibly boosted a little in the short term by the new IMO regulations on bunker fuel, which may see additional amounts of high sulphur fuel oil (HSFO) directed to the power industry. Post 2020, the likely cheapness of HSFO might lead to a greater impetus to installation of scrubbers across shipping fleets, and more refinery integration into petrochemical production, where growth is steadier and more reliable. Peak oil demand, Francis argued, is likely for the 2030-35 timescale.

Meanwhile, as it is difficult to desulphurise residue, the new bunker fuel specification will lead to a real premium for low sulphur crude, and our definition of what is "low sulphur" might be 0.3% sulphur for straight run crudes up to 0.7% for refineries with suitable blendstocks, vacuum distillation etc. About 50% of the current European crude slate is the wrong side of this blend wall, probably leading to more US and Norwegian imports. US crude exports could rise from 2 million bbl/d to 5 million bbl/d, with a concomitantly lower call upon OPEC production. The breakeven cost of new non-OPEC oil production is now only $30-50/bbl, implying that OPEC cannot simply price it out of the market as it has tried to do in the past.

On the gas side, demand is growing steadily, by an additional 20-30% by 2030. Gas and wind power are displacing coal and nuclear, and renewables will represent 30-50% of new global power production by 2040.

Shipping

Brian Malone of Mid-Ship Group noted that the dry bulk shipping index has fallen by 50% since the start of 2019, as trade disputes and China's environmental crackdown impact on iron ore and coal markets, while the aftereffects of the Brazilian mine disaster lead to potentially more mining regulation there and elsewhere. Some good news for shippers has been a 35% increase in scrapping of ships, helping to alleviate what continues to be structural overcapacity in the shipping industry; the fallout from the previous commodity supercycle and financial crisis. Freight rates for handymax and panama vessels are on a rising trade from their historic lows of 2016, but capsize shipping remains at a low point (albeit these ships are generally too large for the sulphur market).

Brian too was concerned about the impact of the IMO 2020 regulations. The operating expense for a ship is generally around $4-7,500/day, depending on size. Bunker fuel prices are in a $43-440/t range in Rotterdam, up from $136/t in 2016, and an even greater shock is expected towards the end of the year in anticipation of January 2020.

Even so, volumes of seaborne trade continue to increase, from 4 billion t/a in 2011 to 5.2 billion t/a in 2018, and with forecast rises of 112 million t/a in 2019 and 120 million or more t/a in 2020. Freight rates remain volatile but are likely to increase as operating costs rise and the overcapacity in the industry gradually dries up.

Adrian Tolson of 2020 Marine Energy expanded on the IMO 2020 theme, noting that late decisions on compliance have led to considerable uncertainty in shipping – many shipowners are only now starting to install scrubbers, and only around 10% of bunker fuel demand will be affected by this by January. This argues for a marine gasoil (MGO) demand spike, as there is still some industry resistance to very low sulphur fuel oil (VLSFO) until shippers gain more experience of using it and find reliable suppliers. This will lead to a 3 million bbl/d drop in HSFO almost overnight from January 2020, and prices falling from around $450/t to $300/t or lower. VLSFO is assumed to settle at a 10% discount to diesel at $500-500/t. Refiners have decisions to make over dealing with their vacuum gasoil (VGO) fraction – is it worth re-starting simple refineries to produce VLSFO? Those with HSFO production will try to maximise coker throughputs, but there is limited excess capacity. This should lead to a price impetus to upgrade HSFO production, especially as power demand and storage capacity may be limited. Some refineries would probably be forced to shut down.

Southern Africa

Steve Sackett gave his usual engaging review of the sulphur and sulphuric acid situation in Southern Africa. The region has 60% of the world's cobalt resources, 68% of its platinum, 10% of its copper and 35% of its manganese, but it also has four of the ten poorest countries in the world. Regional sulphuric acid production has risen from 4.3 million t/a in 2004 to 7.5 million t/a in 2014, and is likely to reach 12.2 million t/a in 2024, but just four countries – South Africa, the DRC, Zambia and Namibia – are the key players.

In the DRC, there is new sulphur burning acid capacity, with production likely to double in the next 5-6 years as new cobalt-copper leaching operations come on stream. From 2019 the country is only likely to import small volumes of acid, with regional repercussions. Zambia has smelter acid which it has traditionally sold to the DRC, but soon will find itself with a 1.1 million t/a surplus and will need tailings projects to soak up the extra acid tonnes. South Africa has seen a decline in acid production due to the exhaustion of various mines, but there are plans for new smelter acid capacity at Paderborn to meet new SO_2 emissions targets. With the DRC once again no longer a customer it remains to be seen where South Africa's excess acid will go. Finally Namibia has three acid plans, most self-contained production; two sulphur burning and one smelter at Tsumeb which sells to Rossing Uranium.

Steve also graphically illustrated the logistical challenges of getting sulphur and acid across an area larger than Europe, and discussed the various ports and routes into the copper belt in the interior.

Phosphates

Alan Pickett, now of Fertecon/Informa, gave the phosphate presentation. Phosphate demand has risen by 2% year on year for the past 50 years to reach 49.8 million t/a P_2O_5 in 2018. Confirmed projects out to the early 2020s will add another 2.5 million t/a P_2O_5, with unconfirmed projects possibly adding up to another 9 million t/a. Alan's prediction for 2024 was 52 million t/a P_2O_5 in terms of production. Demand for 2019 is likely to be roughly the same as 2018, but there are many factors at play, including China's restructuring of its phosphate industry and the US-China trade dispute. Chinese phosphate production will fall by 8 million tonnes product to 2024, and demand by 1.2 million tonnes P_2O_5. This will not remove China from export markets, but will erode its position.

Sulphur and sulphuric acid

Freda Gordon and Fiona Boyd of Acuity Commodities gave the sulphur and acid market presentation. On the supply side, there are a number of new refinery projects and upgrades in India, as well as the Midyan and Fadhili gas plants in Saudi Arabia and new refineries in Nigeria, Saudi Arabia and Kuwait, with several million tonnes of new sulphur capacity due by 2023, most of it in the Middle East. Demand continues to come from phosphate fertilizers, with Morocco, Saudi Arabia and Brazil all bright spots. Nevertheless, the global sulphur balance is forecast to tip into oversupply for the next few years, especially when a potential extra 2 million t/a of sulphur supply from refineries is taken into account due to the IMO regulations. On the sulphuric acid side, China became a net exporter in 2018, a trend likely to continue, while Africa is now the fastest growing region for both new supply and demand.

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Optimising tower design in large sulphuric acid plants

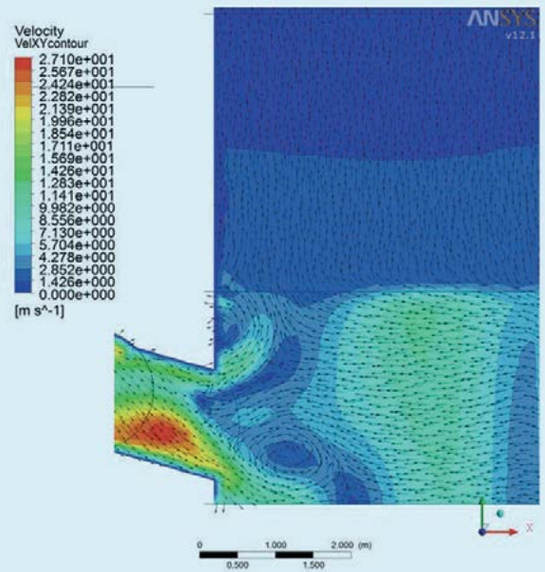
The diameter of acid towers has increased over recent decades to approximately 10 m for a 5,000 t/d acid plant. With the increases in diameter of these larger towers, the coefficient of expansion plays a larger role, not only on the reliability of brick towers but also alloy towers. NORAM Engineering and Constructors outlines current limits for tower diameters and Koch Knight discusses improved methods and materials of constructions for the absorption tower structure and the tower's process internals.

Sulphuric acid towers are used in multiple industries for drying, absorption and stripping operations. These towers are instrumental for the successful operation of sulphuric acid plants (i.e. sulphur-burning, metallurgical and acid regeneration) as well as some gas-cleaning and SO_2 plants. The design of sulphuric acid towers requires an understanding of mass-transfer, hydraulics, packing performance, mist formation and removal, mechanical design, bricking design, corrosion, materials engineering as well as practical engineering and experience.

Sulphuric acid towers have traditionally been constructed of robust brick-lined steel, providing worry-free operation over a wide range of acid temperatures and acid concentrations and excellent longevity, typically lasting 30+ years. Good design practices for brick-lined acid towers include the following features:

- dished bottom for mechanical reliability;
- ceramic dome for packing support strength and unfettered gas flow;
- chip collector screen/vortex breaker;
- Pecora mastic / PTFE lining (or other similar membrane system) to ensure acid does not reach the shell wall;
- low pressure drop high-quality packing to minimise chips and ensure good performance;
- acid distributor with external clean-out;
- 316 L stainless steel top section to minimise sulphate formation;

Fig. 1: **CFD study for gas mixing and distribution in an acid tower**



Source: NORAM

Three large NORAM SX™ alloy towers under construction.

PHOTO: NORAM

- candles with raised flanges for good sealing.

Nowadays alloy metal towers have also become popular. Both types (i.e. bricked and alloy) have benefits and limitations. For example, alloy towers are lighter and have a quicker installation time, often critical in plant retrofits, but require tighter acid concentration control than brick-lined towers, which can withstand the widest possible range of acid concentrations should upset conditions occur. Which tower (alloy or brick) has a lower installed cost depends on the size and installation access. Consideration of the options is required to meet the specific requirements of the plant. NORAM can assist the owner in determining the best option for tower replacement.

Over the past few decades sulphuric acid plants have changed a great deal, not only in size but also the technology, helping companies to either debottleneck existing plants or making step changes in the size of a plant. The typical plant size of 500-1,500 t/d in the 1960s and 1970s has grown to the large 5,000 t/d plants being constructed today.

NORAM Engineering has capabilities in the design, construction and installation of acid towers of all sizes, for multiple applications, and supplies both brick-lined steel and alloy towers. Both types can be designed to provide decades long reliable and trouble-free operation.

NORAM's brick-lined towers include state-of-the-art bricking, with innovative stable dished bottoms, self-supporting dome packing support, and internal or external water dilution. The mechanical design limit for NORAM brick-lined towers is 10 m diameter, which is typically required for a 5,000 t/d acid tower. This limitation is given by the dome mechanical strength. Larger plants that require brick-lining would have to stay within that diameter limit, or use a different type of packing support, or may need two towers operating in parallel. As an alternative, NORAM SX towers could be implemented of larger diameter.

NORAM's alloy towers are fabricated in high-silicon stainless steel (NORAM SX™, UNS 23615). There are no mechanical limits to the diameter of the tower if it is made of NORAM SX with a metallic support grid made of the same material. This type of tower can be designed for plants larger than 5,000 t/d and have diameters in excess of 10 m.

NORAM caries out CFD calculations (Fig. 1) to ensure adequate gas distribution is observed in the towers. This issue becomes more important for larger towers. If the gas concentration of the plant is increased, an acid tower can accommodate larger acid production capacity.

Sizing of absorption acid towers

The diameter of an acid tower depends on many factors such as:

- gas flow;
- liquid flow;
- packing type;
- target pressure drop;
- diameter to fit existing footprint;
- considerations for future expansion.

The required packing height depends on the mass transfer rate and the absorption efficiency required. Acid towers require packing to achieve intimate contact between gas and liquid.

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Optimising tower design

At the recent 2018 Sulphur + Sulphuric Acid Conference, Koch Knight highlighted that some sulphuric acid plants with tower diameters that exceed those of the previous generation have experienced an increase in failures. With the increases in the diameter of these larger towers, the coefficient of thermal expansion plays a larger role, not only on the reliability of brick towers but also alloy towers.

They suggest that while a great deal effort has been placed on the process side and the catalyst, in some plant designs not as much effort has been placed on the issues associated with the step changes in the tower sizes as well as the operational and construction costs.

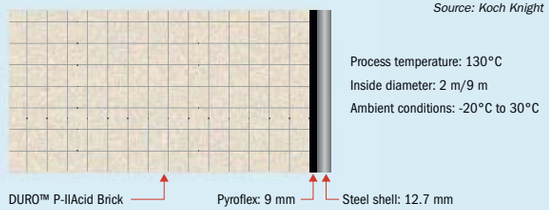
Recently, Koch Knight has reviewed the repair work required by new plants. Common issues are seen in the larger plants. Knight has addressed these issues with a two-pronged approach. The first was to create a repair method to quickly repair leaks and lining deficiencies in existing sulphuric acid towers. Koch Knight developed a proprietary novolac pumping resin to repair issues on these towers and have since used this material on over 25 towers up to 10 m in diameter. But as the novolac injection material helped solve a short-term issue the underlying root cause was not uncovered.

As more information became available on the towers that were being repaired, common locations of the failures and time in service started to show a pattern. To better understand this issue, information was collected which included the diameter of the towers, the type of acid brick, membrane materials as well as environmental issues such as external temperatures, wind loading and potential for seismic activity from each of the locations of the failures.

A pattern was recognised, centred on the diameter of the towers and the type of acid resistant membrane that was used in the brick lined towers. While other causes should not be discounted they were not explored in detail for this presentation. After evaluating this data, it was determined that the use of FEA could be used to uncover any additional issues or confirm some of the assumptions that were being considered. The initial work was done using ambient temperature changes between day time and night time temperatures. It became obvious that as the diameter increased, just the delta in the day and night time temperatures could be an issue alone.

Fig. 2: **Model of lining system for Pyroflex® sheet lining case**

Source: Koch Knight



Relative thermal expansion of the steel shell to the brick lining

At operating temperatures, the expansion and contraction of the different materials causes relative movement or loading in a structure, especially when you utilise two different materials with very different coefficients of thermal expansion (CTE) such as ceramic brick and steel. In an FEA study the relative thermal expansion was compared between the inner brick lining and the outer steel shell for two different diameters and at two different ambient temperatures. To cover the range of existing towers diameters of 2 m and 9 m were selected. Assuming installation at 20°C, worst case ambient temperatures during operation of -20°C and 30°C were used in the calculations.

The purpose of the study was to determine whether under certain conditions a gap would occur between the brick and the steel when the expansion of the steel was greater than that of the brick.

The same conditions were also evaluated with Pyroflex® acid resistant sheet lining which has a significantly higher CTE than either the brick or steel to determine if it would compensate and fill any gaps that occurred.

Fig. 2 shows a model of the lining system for the Pyroflex® sheet lining case. From the results it is evident that there is a noticeable difference in the radial displacement profiles between the 2-m and 9-m diameter towers as well as with cold and warm ambient temperatures.

Figs 3-6 show the radial displacement of each lining configuration. This is the amount each point moves away from its original position based on the distance measured from the centre line. In this case the original position is considered to be at a temperatures of 20°C inside and outside without any stresses in the lining as would be the case after it was constructed.

Under warm ambient conditions, the steel shell expands due to the temperature change and moves away from the centre line (radius increases). The brick lining will also expand and move away from the centre line and press against the shell, or if the expansion of the steel shell is too great, a gap will occur between the steel shell and the brick lining.

The smaller diameter tower (Fig. 3) shows a continuum between the cold end of the brick lining and the inner part of the steel shell, indicating that the two linings remain in contact with each other. However, in the case of cold ambient conditions the pressure of the bricks against the shell will be slightly more as there is a slightly lower steel expansion compared to the warm ambient condition of the shell. The amount it touches will be evident in the stresses that are created.

In Fig. 4 for the larger diameter tower there is a large jump (warm ambient conditions) between the cold end of the brick lining and the steel shell, indicating that there is a gap; the shell moves away further from the centre line than the brick lining. The red profile shows that the steel expanded more than the refractory lining and will therefore create a gap the size of approx. 0.27 mm (2.51 mm - 2.24 mm).

This illustrates that as the tower diameter and ambient temperature increases, the gaps can occur during peak temperatures each day. This is a dynamic system with the gap dimension cycling with normal temperature variations between night and day. This condition will likely be the most prominent in desert and mountain conditions where there is a large differential between daytime and night time ambient temperatures. Additional data is being gathered at this time on addition locations around the globe.

Acid brick lining systems have some porosity and may have other acid flow paths due to imperfections or through the mortar joints. The dynamic system created by the reoccurring gap will cause active flow between the brick lining and the steel shell potentially washing away any passivating layer that forms and initiating corrosion of the steel shell. The remedy for this phenomenon is to protect the steel shell with an acid resistant membrane before installing the acid brick lining.

In the past the preferred membrane material was a trowelled-on acid resistant mastic which performed well on smaller towers lasting years with little or no maintenance. The major issue is that the trowelled-on material solidifies over time or when it comes in contact with sulphuric acid. And under the stress and compressional forces due to the brick/shell movement will crack or abrade the material over time due to the lack of elasticity after the material has solidified. In addition, it is difficult to control the thickness of the mastic which can result in a thinner than desired installation.

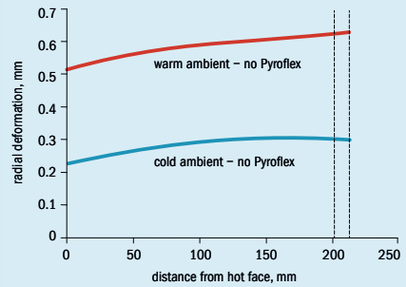
An alternative membrane option is Pyroflex® acid resistant sheet lining which addresses both the need for a corrosion barrier and a mechanical means to prevent the gaps better the acid brick lining and the steel shell. When Pyroflex® is introduced to the system a complex range of things happens. Due to the high coefficient of thermal expansion of the Pyroflex® sheet lining, it fills the space between the steel shell and refractory in such a way that it forces the shell to move, not only due to temperature, but also due to the pressure it applies to the shell on one side and the brick lining preventing it to move into the opposite direction. The expanding refractory lining is compressing the Pyroflex® sheet lining and this results in the sharp dip in the graph shown in Fig. 5 at the refractory/membrane interface.

Under cold ambient conditions the steel shell is expanding less compared to the high ambient conditions.

In this case, for both the small and large diameter towers the refractory is pressing more against the steel shell. This is evident in the higher compression stresses formed within the refractory lining.

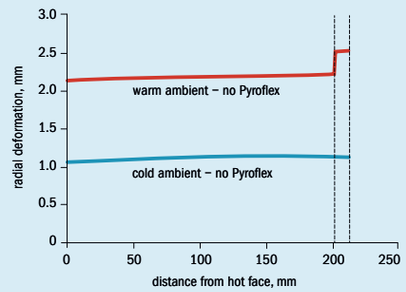
The insulation effect of the Pyroflex® acid resistant sheet lining along with its high thermal expansion properties, make for some dramatic changes between the blue (cold ambient) and red (warm ambient) lines in Fig. 5 which considers a small

Fig. 3: **Radial displacement of the 2 m tower without membrane**



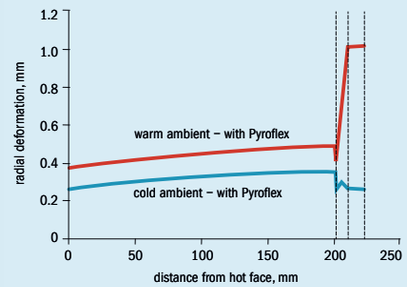
Source: Koch Knight

Fig. 4: **Radial displacement of the 9 m tower without membrane**



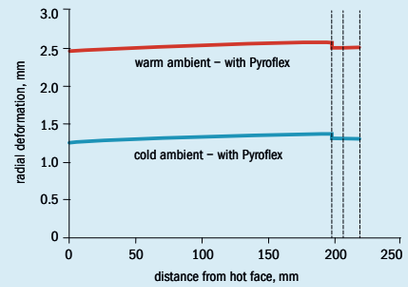
Source: Koch Knight

Fig. 5: **Radial displacement of the 2 m tower with Pyroflex**



Source: Koch Knight

Fig. 6: **Radial displacement of the 9 m tower with Pyroflex**



Source: Koch Knight

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BCInsight

Southbank House, Black Prince Road
London SE1 7SJ, England
Tel: +44 (0)20 7793 2567
Fax: +44 (0)20 7793 2577
Web: www.bcinsight.com
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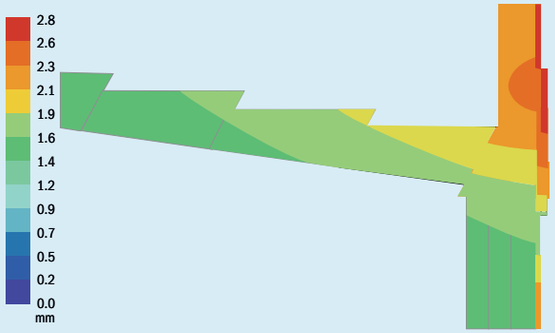
Fig. 7: **Radial displacement at packing support for tower operation at 130°**



Source: Koch Knight

Table 1: **Tower diameters according to packing type**

Size of the plant (t/d)	3 inch standard saddles (diameter/volume)	Flexeramic®-88 (diameter/volume)
500	3.4 m / 30 m³	2.8 m / 20 m³
1,000	4.7m / 50 m³	4.0 m / 40 m³
2,000	6.7 m / 110 m³	5.7 m / 80 m³
3,000	8.2 m / 160 m³	7.0 m / 110 m³
4,000	9.5 m / 210 m³	8.1 m / 150 m³
5,000	10.6 m / 260 m³	9.0 m / 190 m³

Source: Koch Knight

diameter tower. The effect of shell movement and ambient conditions are less noticeable when a larger diameter tower is concerned (Fig. 6). For the larger tower the sudden drop in both the profiles indicate that the bricks expand more than the steel shell. In each case no gap occurs, and the brick lining system is maintained in compression.

The more complex condition at the packing support dome was also considered. There are major temperature differences, mainly due to the sudden change from three to two layers of brick lining below and above the dome. As shown in Fig. 7 complexity increases the gaps created and can result in acid trapped and the circulated at the steel shell. The addition of a membrane such as Pyroflex® acid resistant sheet lining can compensate for the discontinuities in this area by conforming to and filling any gaps.

Although not considered in this study the lining around the gas inlets present a similar challenge. The more complex geometry increases the opportunity for gaps and high stresses.

On exposure of the models to the operating temperature the bricks will thermally expand and create a force towards the sidewalls, hence pushing against the sidewalls. The shell with a retaining ring around it will resist some of this movement and create an upwards movement of the dome. Depending on the ambient conditions, which directly affects the expansion of the steel and therefore the diameter of the vessel, the vertical lift will be different for each case. Higher shell temperatures would result in lower lift, whereas cooler shell temperatures will result in a higher lift of the dome.

The Pyroflex® acid resistant sheet lining also contributes to differences in the movement of the dome.

Pyroflex® sheet lining impacts two distinct properties which affects the behaviour of the brick lining. The insulation property lowers the shell temperature and increases the brick lining temperature and the thermal expansion of the Pyroflex® sheet lining and its compressibility increases the stress in the lining, e.g. it pushes the brick lining away from the shell, as Pyroflex® sheet lining has some degree of ductility at these operating temperatures. This is evident in the results from the modelling as it shows higher lifts of the dome when Pyroflex® sheet lining is installed.

Reducing tower size through packing selection

In addition to the reduced capital cost, it is also desirable to reduce the diameter of sulphuric acid towers to improve the performance and reliability of the lining system. This can be accomplished by using structured packings in place of random packing.

From a new plant prospective based on multiple sources a savings of up to 15% of a tower cost could be achieved by evaluating structured packing vs a standard 3" saddle, due to the reduction of the tower diameter.

Table 1 illustrates the implications related to going from a standard 3 inch (75 mm) saddle to a Flexeramic® 88 ceramic structured packing. The table shows the tower diameters based on different packing types.

In summary, if you want to be able to debottleneck your plant in the future on a larger plant, design the plant with saddles but use Pyroflex® acid resistant sheet lining to avoid the additional stresses. Alternatively reduce the size of the plant tower diameter by using a structured packing and reducing the power consumption on the blower. Either option provides a viable step change.

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Fax: +44 (0)20 7793 2577
Web: www.bcinsight.com
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Utilising data to your biggest advantage

PHOTO: SHUTZ / ISTOCKPHOTO.COM

Big data is big news in today's data driven world. Big data projects often use cutting-edge analytics involving artificial intelligence and require huge volumes of data to power machine learning and deep learning algorithms that lead to real-time insight. In this article we take a look at some examples of how big data and digitalisation is being utilised in the sulphur and sulphuric acid industries.

The digital revolution has changed the face of many industries and is creating pressure on businesses to transform their strategies and operations to meet the changing needs of their customers. Since the dawn of the digital age there has been an explosion in the amount of data we generate and the amount of data we're creating continues to increase rapidly. The term "big data" refers to the collection of all this data and our ability to use it to our advantage across a wide range of areas, including business. To succeed in a data driven world, businesses need to analyse and act on their data to identify new sources of revenue, deepen customer engagement, and reduce costs.

Big data is an evolving term that describes a large volume of structured, semi-structured and unstructured data that has the potential to be mined for information and used in machine learning projects and other advanced analytics applications. Big data affects organisations across practically every industry. In manufacturing, armed with insight that big data can provide, manufacturers can boost quality and output while minimising waste. More and more manufacturers are working in an analytics-based culture, which means they can solve problems faster and make more agile business decisions.

Big data works on the principle that the more you know about anything or any situation, the more reliably you can gain new insights and make predictions about what will happen in the future. By comparing more data points, relationships begin to emerge that were previously hidden, and these relationships enable us to learn and make smarter decisions. Most commonly, this is done through a process that involves building models, based on the data we can collect, and then running simulations, tweaking the value of data points each time and monitoring how it impacts our results. This process is automated – today's advanced analytics technology will run millions of these simulations, tweaking all the possible variables until it finds a pattern, or provides an insight, that helps solve the problem it is working on.

In this article we take a look at some examples of how big data and digitalisation is being utilised in the sulphur and sulphuric acid industries.

The first step towards digital transformation is digitisation – the process of making information available and accessible in a digital format. Once analog data has been digitised, there is enormous potential for applications that facilitate standard work practices.

The next step is digitalisation – the integration of digital technologies into everyday life by the digitisation of everything that can be digitised. Digitalisation is all about making digitised information work for you. In modern plant operation the use of digitalisation will increasingly play an important role, be it for safety, environmental or for plant optimisation.

These steps are required to progress to digital transformation, which can be described as the transformation of business and organisational activities, processes, competencies and models to enable organisations to use and exploit digital technologies to improve business processes and outcomes.

nVent sulphur pipeline management

How do you ensure that you have the best trained professionals to operate a sulphur pipeline in the safest and most reliable way? The key is to leverage as much information as is available during both normal operations and extreme events, (such as re-melting plugged sulphur or during minimum flow operation).

As the potential exists for sulphur cool down and/or re-melting to occur at different rates in various portions of the pipeline, it is imperative to perform pipeline operations and maintenance activities in a manner that does not create overpressure, overheating or other pipeline failure scenarios. Localised thermal discontinuities (from a heat transfer perspective) can create a complex and dynamic environment along a sulphur pipeline, making it difficult to manage. These discontinuities could include pipeline void spaces, excessive heat loss zones and the impact of elevation changes along the alignment.

Until now, the potential to utilise big data and artificial intelligence (AI) to manage sulphur transport pipelines has been largely untapped. nVent Thermal Management (nVent) is steering the way with its industry leading approach for a safe and reliable heated sulphur pipeline management program in a customised software. Utilising the compelling pipeline operating data extracted from a fibre optic distributed temperature sensing (DTS) system on the pipeline, combined with other pipeline and electrical equipment instrumentation, decision-based outcomes become much more predictable by leveraging the enormous amount of available data.

The benefits of utilising AI on a pipeline are many, offering both operating efficiencies and the reduction of risk:

- improved operating efficiency and reduced electricity ;costs;
- increased asset utilisation and maximised throughput
- optimising pump utilisation and minimising pump downtime (flow interruption);
- reducing unscheduled pump maintenance/extending service life of pumps;
- reduced maintenance costs;
- environmental stewardship and improved human safety.

What if you could keep your pipeline flowing, or ready to flow at all times? Moving into the era of AI allows for proactive and predictive analysis, giving operators the ability to address a potential problematic scenario before it becomes a crisis. Utilising data and customised algorithm-based software, it is possible to add a virtual pipeline "analysis expert" to your staff. The good news is that the algorithms work around the clock, with no time off – they become a 24-hour-a-day member of your team.

The human brain

There is something called Moore's Law (an observation made by Intel co-founder Gordon Moore), which basically states that computing power doubles every 18 months. Moore's Law suggests exponential growth, though it is unlikely to continue indefinitely. Nonetheless, that is a staggering concept, and explains the phenomenal growth of computer technology applied to real life situations. Transport pipelines are not exempt; technology is advancing at a rapid pace. The ability to utilise streaming fibre optic distributed temperature data from a sulphur pipeline can produce enormously valuable insight for a pipeline operator. The question becomes, what will that operator do with this insight?

Limitations of the mind

Typical of most individuals in their occupational endeavours, a myriad of necessary job activities compete for our limited time during any given day. Thus, we attempt to prioritise those tasks to fit the time we have to spend on them, often leaving us with unfinished business. This becomes especially true when it comes to using our own cognitive thinking and performing detailed analysis of complex situations. Unfortunately, the human brain has a limited capacity to segregate and assimilate "useful" information, and so what should be data-driven decisions sometimes become a matter of one's opinion or judgement. The current best practice to manage a heated sulphur pipeline from day to day is to rely solely on skilled operators to manage the complexity of the sulphur pipeline.

Could computers help us leverage our time and talent by offloading some of the responsibility to machines? The answer is absolutely yes. The real value of this approach is that computers never take a day off and they don't make a mistake (at least if it is programmed properly). Humans do, on both counts.

Rational versus emotional decision making

First of all, it is worthwhile to understand a little bit about the most amazing aspect of humankind… the human brain. Some have said that the human brain may be able to hold as much information in its memory as is contained on the entire Internet. No other animal or thing on the planet has the ability to assimilate thousands upon thousands of inputs and perform cognitive reasoning like the human brain. We call it decision making. Cognitive thinking is described as: "of or pertaining to the mental processes of perception, memory, judgment, and reasoning."

Experts will tell you there are two types of decision-making conducted by our brain – rational and emotional. Rational thinking is where an individual will think in a logically consistent way. Often, rational thinkers see the world as a puzzle or machine where their actions change the circumstances and thus the end result. Often, this type of thinking can be considered as A+B=C.

Emotional thinkers, on the other hand, often see the world through the lenses of how their actions make an individual or group feel, also known as "empathy". These individuals have the ability to notice the value of things that do not directly benefit themselves. Their weakness is that often this becomes short-sighted in nature. At the end of the day, emotional responses may not have a rational outcome.

The power of computing

The beauty of computing is that it can be programmed to make determinations (or, decisions) based solely on input data, by introducing algorithms that create rule-based outcomes. It is not emotional, and it does not have a "bad day" every once in a while, like we humans do. The examples of using computing software today to benefit us are endless. One only has to look at what has been accomplished already by machines using customised and complex algorithms. There is targeted advertising based on your unique buying patterns, or fraud prevention software for credit card users and map applications that select an optimum route and a predicted arrival time. These all utilise complex algorithms to get the job done.

Flow assurance

So what does the human brain have to do with pipelines? Well, what every pipeline owner/operator wants to do is to go to sleep at night and not awaken to a pipeline problem – the pumps deadheaded; the line jumped off the pipe rack; or, your worst nightmare… "we've experienced a

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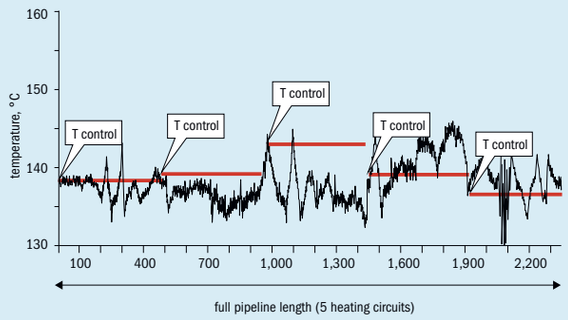
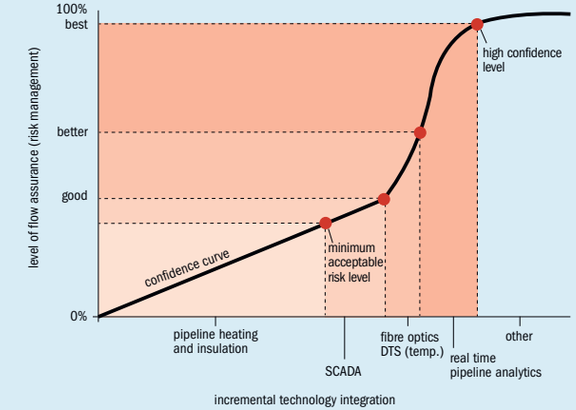
Fig. 1: **Fibre optic distributed temperature sensor profile for a sulphur pipeline**



Source: nVent

Fig. 2: **Incremental value of flow assurance through software**



Source: nVent

rupture". Basically, it boils down to flow assurance – the peace of mind to know that you are taking all of the proper precautions to operate and maintain your pipeline safely and reliably.

How can you achieve this state of mind? The answer is, to build the proper foundation for your pipeline technology and to apply that technology in a way that gives you the best opportunity to see a problem coming. The recent advances of fibre optic DTS have the potential to revolutionise the world of pipeline operation and maintenance, as it relates to flow assurance.

Limitations of point sensing control and monitoring

The long-time conventional method of collecting data for heater control on a heated pipeline has been to rely on discrete sensing points at the front or back end of a pipeline. When relying on point-sensing temperature control the temperature along a pipeline is often assumed to be uniform, or constant, along its length. In this scenario the on/off control for heat is dictated by a single sensing point. However, the actual temperature is not uniform as many people assume, for a myriad of reasons.

The black line in Fig. 1 is a DTS temperature profile (at a point in time) for five back-to-back heating circuits, with temperature on the vertical axis (y-axis) and line length along the bottom (x-axis). In this scenario, a 24-km pipeline is divided into five heating circuits (segments) and incorporates a fibre optic DTS system that monitors the temperature for the entire pipeline. Each heating circuit has a controlling RTD measuring the pipe temperature near the beginning of the circuit (flow direction is left to right).

As shown in Fig. 1, if a pipeline operator assumed that an entire heated circuit exhibited the same temperature as a single RTD (Tcontrol) reading at the beginning, it could be a grossly incorrect assessment for that circuit.

For many reasons, each circuit segment exhibits temperatures that range between 5-10°C above and below the desired set-point of 135°C. Those reasons may be from non-uniformity in the thermal insulation system, the presence of heat sinks along the pipeline (such as vents and drains), or even the effects of elevation changes. Furthermore, the effect of differing ambient conditions such as temperature swings, solar exposure levels, wind, rain, snow and sand buildup around the pipeline can cause thermal discontinuity in the temperature profile of a long pipeline. Understanding all these complexities and dynamic changes is important when dealing with flow assurance for a sulphur pipeline. In a continually changing environment, constant analysis of this data while tracking the changes is an impossible task for any human.

Leveraging technology to improve flow assurance

So, how does one find the holy grail of flow assurance for a sulphur pipeline? Flow Assurance can be partially implemented through well planned engineering and design. For a sulphur pipeline, one can incorporate design features such as full (100%) redundancy, multiple power (heat) output levels, pressure relief strategies and proper safety factors.

However, flow assurance also requires the prudent use of technologies. Until recently, Flow Assurance for temperature critical fluids such as sulphur has relied strictly on only pipeline heating and thermal insulation. A few of these systems have required that temperature and electrical data information be sent from the heating control panels to the process distributed control system (DCS) and/or to the supervisory control and data acquisition (SCADA). By doing this, the level of flow assurance is increased slightly with some operational data. This concept is depicted in Fig. 2, which shows that a pipeline can climb the "confidence curve" for flow assurance with the addition of technology. The added benefit of a system like SCADA increases the level of confidence that your pipeline will flow all of the time.

More recently, especially on long sulphur pipelines, another level of growth toward complete flow assurance has been made available by incorporating fibre optic DTS to monitor the temperature of the entire pipeline. This enhancement offers a significant leap forward, as pipeline operators are no longer blindly operating the heating system, especially during abnormal conditions such as low flow or re-melt. However, the use of streaming DTS still requires constant monitoring of the system by human beings, with the risk that critical data goes unnoticed or is lost.

Finally, the next available technology step to improve flow assurance is to implement real-time advanced analytics in the form of flow assurance software. Custom algorithms interpret the streaming data coming from DTS to create data-driven assessments and suggest actionable tasks to mitigate a potential problem that may be occurring. The ability for software to track temperature trends over time is a huge advantage and time saver.

By incorporation of advanced analytics the point on the confidence curve on the flow assurance graph rises to a very high level that largely eliminates human error. This enormous incremental improvement in the flow assurance is shown in Fig. 2 as the "high confidence level". (Note that the values for Flow Assurance and incremental technology integration are not absolute and are only shown for illustrative purposes).

The power of advanced analytics

Advanced analytics combines the ability to deliver immediate information based on processing high definition data, from both real-time and historical sources in a consistent, detailed, and error free manner. This is illustrated in Fig. 3.

Data analysis

Processing high definition data requires the development of specialised algorithms that can consistently and reliably identify the critical information contained in the relevant data sets. The challenge lies in the fact that, most of the time, the data simply indicates that the system is operating normally, and false alarms only serve to undermine any system's effectiveness in generating a prompt response to the concerns raised by the system.

Algorithms must make the best use of multiple data sources to confirm trends seen in a single key variable, and historical behaviour must be compared with real-time data to increase confidence. Only by the application of advanced analytics can the available disparate data sources be simultaneously analysed in an integrated fashion to generate the highest possible level of confidence in determining the status of the asset being monitored.

The advanced analytics tools increase the end user's confidence in the system by correlating data across previously discrete systems. Data is further processed by the calculation of gradients and by data averaging. These techniques allow the system to identify certain types of events through the real time rate of change in the data, while identifying other classes of events by improving data resolution (by averaging out sensor noise over time) to detect small but significant trends in the data.

The use of advanced analytics enabled by high density data collection, available processing hardware, and recently developed data management technology brings pipeline operators new levels of actionable operational and maintenance information and overall monitoring confidence.

Identifying actionable information

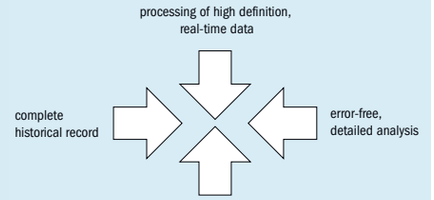
By combining advanced analytics and agile software development, tools can be generated to efficiently convert high definition data into actionable information. This is illustrated in Fig. 4. However, this is not so easy as to simply develop and code smart algorithms. The software framework must also be developed to collect and stage the high definition data from the various systems where it is available. System architecture requires attention to different data formats and the data transfer protocols supported by a wide range of legacy data collection and archival systems.

In addition to accessing data from legacy sources, system databases must fully stage all data required by the advanced analytics algorithms within the defined measurement cycle. This includes some data pre-processing and data verification; in other words, invalid Data = invalid Information.

Pipeline reference data must also be managed. This includes pipeline model parameters which are defined during design and construction, like the location of pipe bridges, underground/culvert segments, elevation, etc., as well as critical baseline performance parameters for the asset.

Lastly, the software must have some interface whereby actionable information can be passed along to the operating company's personnel in a clear and concise manner. Only after each of these required functions has been addressed, can the software fully implement an Advanced Analytics framework.

Fig. 3: **Leveraging the strengths of advanced analytics**



Source: nVent

Fig. 4: **Converting high definition real-time data to actionable information**

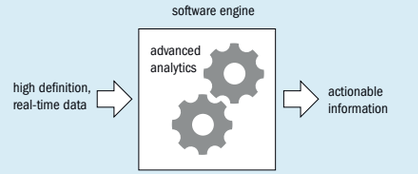


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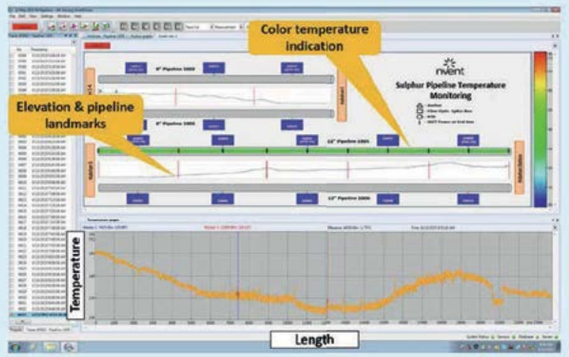
Fig. 5: **User interface**



Source: nVent

Evolution of fibre optics applied to sulphur pipelines

Heated pipeline technology has evolved tremendously in the last 50 years, from development of heating cables to control and monitoring systems. The emergence of fibre optic distributed temperature based technology in recent years has become a big part of the story. The advances in technology and lowering of costs has made DTS a very appealing technology for all types of pipelines, but particularly those which carry temperature-critical fluids, like molten sulphur.

The past and present state

Electric trace heating systems in the past (and even present day) use point sensing for temperature control. Ambient sensing thermostats or RTDs are used to control "freeze protection" circuits. For "process temperature maintain" applications, one or two temperature sensors are used to sense the temperature of the pipe itself and the entire associated heating circuit is energised based on those temperature inputs. This has been sufficient for most applications, where the desired maintain temperature has a relatively wide control range.

For applications like sulphur that have a narrow temperature range, the design rules are a bit more strict and call for additional measures such as limiting the heating circuit to one flow path only and creating a high temperature cut-off of the heating system by using a separate controller and sensor. In the case of long pipelines with temperature critical fluids such as sulphur, designs sometimes call for multiple temperature sensors to be installed along the length of the pipeline; however, sensor locations are limited by long distance issues with sensor cabling and no matter how sensors are installed, it is impossible to get temperature data from every location of the pipeline.

In 2004 the concept of using fibre optic distributed temperature sensing (FO DTS) for monitoring the temperature of the entire length of a heated sulphur pipeline was introduced in an IEEE PCIC paper "Controlling skin effect heat traced liquid sulphur pipelines with fibre optics".

In a FO DTS system, a pulsed laser is coupled to an optical fibre located on the pipeline through a directional coupler. The laser's light is backscattered as the pulse propagates through the fibre's core owing to changes in density and composition as well as molecular and bulk vibrations. In a homogeneous fibre, the intensity of the sampled backscattered light decays exponentially with time. Because the velocity of light propagation in the optical fibre is well known, the distance can be calculated from the deterministic collection time of the backscattered light.

The measured temperature and distance can be identified simultaneously, with one-metre spatial resolution and one-degree Celsius temperature accuracy. Temperature information gathered from the FO DTS system is normally displayed in user-friendly screens that provide operations and maintenance personnel with temperature profiles for the entire length of the pipeline. If hot or cold temperature spots appear on the pipeline, the operator can easily zoom in to the affected area and alert maintenance staff, (within one meter), to the exact location of the problem. A sample user interface is referenced in Fig. 5.

Starting in 2006 the concept of utilising fibre optics was applied to long sulphur pipelines in Canada and the Middle East. Today, there are more than 200 kilometres of temperature sensing FO cable installed on sulphur, phenol and vacuum gas oil (VGO) pipelines. In all of those applications, the FO system is only used for temperature monitoring, not for heating system control. The reasons for this are two-fold. First, most of these systems are installed in conjunction with the skin-effect trace heating system and until recently, the standard for this heating technology was IEEE 844-2000, which did not recognise fibre optic temperature sensing as an allowable temperature sensing method; this changed in 2017 when IEEE 844 was updated [reference new IEEE/CSA standard] allowing the use of FO as a temperature sensing method for skin-effect trace heated lines. Secondly, as with any other new technology application, it takes some time for the technology to be proven and for the industry to feel comfortable adopting that technology.

The future state

Since its first application on a long sulphur pipeline, FO DTS temperature monitoring showed its great potential. Initially conceived primarily as a technology that would aid Sulphur pipeline operators safely through the tricky Sulphur re-melt operation, it quickly became apparent that its use would extend much further. For instance, in one of the first two pipelines mentioned above, FO DTS temperature monitoring played an invaluable role by revealing multiple thermal insulation deficiencies caused by poorly-installed field joint insulation on a pre-insulated pipeline. In another project the FO DTS system quickly and accurately helped commissioning personnel identify design/construction issues with pipeline anchors and supports. There was even an instance of electrical fault-location inferred from FO temperature readings that has been documented. All of these examples required extensive manual review and analysis of the DTS data over periods of time. It was a time-consuming and painstaking process.

Until now, there has been no "real time" analysis tool available to identify problematic conditions on a pipeline to drive actionable decisions. It stands to reason that software can be an enormously powerful tool when coupled with streaming temperature data from DTS. The ability to track changes over time creates nearly unlimited types of analyses that are useful to pipeline operators. Below are just some of the tendencies that can be identified with advance analytics software in affiliation with DTS:

- pipeline fill percentage;
- flow restrictions;
- plug prediction;
- pipeline troubleshooting;
- heating system health;
- insulation integrity;
- predicted time to freeze;
- hot/cold spot location;
- re-melt assistance;
- rupture detection;
- as-built quality.

Additionally, the notification aspect of software can proactively communicate with e-mails or texts (SMS) to various personnel in the organisation, prompting swift action. Pre-determined rules can even organise to whom these messages are sent, based on the level of situation severity.

The next step

The logical next step in software is to incorporate AI for the data gathered. Over time, it is possible to identify tendencies of a pipeline's operation based on historical temperature data and other inputs. The algorithms expand and make use of Machine Learning and Artificial Intelligence.

This allows the pipeline management to become ever more prognostic. For example, the pipeline operator could input risk tolerance preferences and/or desired operating cost targets and the adaptive software would adjust the system toward the desired target on a continuous basis. This is known as creating artificial intelligence.

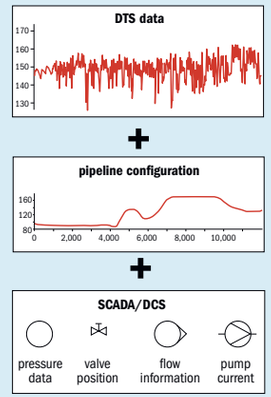
nVent's flow assurance software

nVent, in cooperation with its partner AKOS, has developed a new generation of software, to bring advanced analytics to pipeline management. The initial product release targets heated pipelines and contains several specialised algorithms specifically developed to address the challenges of sulphur pipelines.

The flow assurance software package offers predictive analytics by combining data from fibre optic DTS and conventional sensor systems on the pipeline. It provides real time status of a heated pipeline – temperature, percent fill, phase change status, re-melt, rupture detection and much more. Proactive messages are sent to pre-designated end user operations and maintenance personnel, with customised permission rights that are based on situational level of urgency.

Any pipeline with fibre optic DTS can use nVent's flow assurance software. The software program is data source agnostic, in that it does not need to be coupled with a specific DTS manufacturer's instrument to work.

Fig. 6: **Core pipeline data sources**



Source: nVent

Data sources

The flow assurance software draws high definition data from three primary sources, illustrated in Fig. 6.

The first form of core data is distributed temperature sensor (DTS) data. Ideally, the DTS data is collected every half metre at a minimum interval of five minutes. As the software compares trends in historical data with the real time data being collected, the system improves its ability to identify key information in the DTS data over time. In general, a minimum of one year's DTS data is kept in the database utilised by the flow assurance software.

The second form of core data is pipeline configuration data. This data is used to characterise the unique attributes that make up an individual pipeline. It includes information required by the algorithms to explain certain behaviours in the system data. Information about the pipeline layout, the location of pipe bridges and underground/culvert sections, the location of vents and drains, the location of anchor points, etc. The flow assurance software uses this pipeline configuration data to determine which algorithm variants should be applied to specific locations along the pipeline.

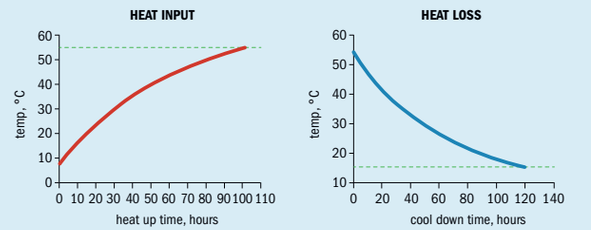
The final form of core data is SCADA/DCS data. The flow assurance software interfaces with the legacy SCADA/DCS system in the plant to access key parameter data related to pump speeds or flows, inlet and outlet pressure, inlet and outlet temperatures, etc. This data is co-analysed with the DTS and pipeline configuration data to improve the overall reliability and robustness of the algorithm package.

Pipeline characterisation

The actual algorithms (as well as the specific data stream inputs) used by the flow assurance software are proprietary. However, Fig. 7, gives some high-level insight into a few of the basic principles employed.

This figure illustrates the fundamental heating and cooling characteristics that

Fig. 7: **Baseline pipeline behaviour**



Source: nVent

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Fig. 8: **Proactive messaging for actionable tasks**

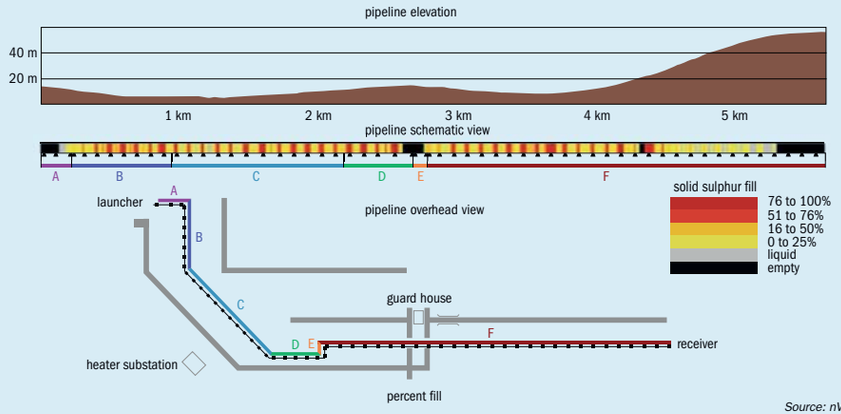
FLOW ASSURANCE
(operations messaging)
"Flow 40% restricted at 3,693 metres"
- Leak detection and location
- Pipeline plug detection and location
- Flow restriction characterisation
- Distributed pipeline fill percentage
- Void space location and tracking

KEY COMPONENT INTEGRITY
(maintenance messaging)
"Heat loss in insulation at 432 metres"
- Heating system monitoring
- Insulation health monitoring
- Anchor heat loss characterisation
- Anchor integrity tracking
- Water ingress monitoring

CRITICAL SITUATION MANAGEMENT
"16 hours until pipeline freeze"
- Freeze prediction and tracking
- Auto-Melt™
- Convective flow analysis
- Vent and drain coordination
- Rupture conditions warning

Source: nVent

Fig. 9: **Actual, real-time state of sulphur as it is freezing in a pipeline where the heating system has been de-energised**



Source: nVent

result from the physical properties of the pipeline. The heat input graph shows how a given section of the pipeline increases in temperature as the heating system is energised, and the heat loss graph shows how the pipeline decreases in temperature as the heating system is de-energised. Both graphs are for an empty pipeline. The flow assurance software generates this baseline information for each half-metre section of pipeline.

By accounting for ambient weather conditions, input product temperature, pipeline fill percentage, and other key variables; the rate at which the heater is supplying heat to the pipeline in that section can be estimated. This can then be compared to the power being applied to the heater circuit to see if the heater is functioning properly or to determine if a different power output level needs to be applied. Comparative data time trends also indicate if the system is stable or trending in a direction that requires attention.

Similarly, the cooling rate can be corrected to account for the variables known to be influencing the measured rate to determine if a particular pipeline section's heat loss is within the "normal" window or if something material has changed in the pipeline's insulation, cladding, etc.

It is only through this continuous (over time), section by section analysis that potential problems with the heater and/or the insulation envelope can be detected early and accurately. The flow assurance software algorithms that manage these functions incorporate real-time, historical, DTS, SCADA/DCS, and pipeline configuration data to produce reliable and accurate actionable information.

Software output

The flow assurance software provides actionable information to system users and directs specific messaging to users according to their functional roles and responsibility level within their function. The system is divided into three modules as illustrated in Fig. 8.

The software also supports a system console that graphically displays the current status of each of the pipeline properties being monitored by the advanced analytics algorithms. This visualisation tool is generally available at the pipeline's master control console where it can be easily accessed by operations, maintenance, or instrumentation staff. The example in Fig. 9 shows the actual, real time state of the sulphur as it is freezing in a pipeline where the heating system has been de-energised.

The flow assurance software also provides an interface to deliver warning and alarm messages via the plant's legacy SCADA/DCS system.

Table 1: **Example cost savings with flow assurance software**

Category	Annual savings
Reduced electricity costs	$122,000
Extend service life of pumps	$150,000
Unscheduled pump maintenance	$ 75,000
Pump downtime / flow interruption	$100,000
Total savings	**$447,000**

Source: nVent

What about re-melt?

The software's patented re-melt module (AUTO-Melt™) utilises known sulphur properties and behaviour through phase change to enormously reduce the chance of pipeline over-pressurisation, due to product expansion between plugged pipeline sections. The software can identify areas where valuable heat is escaping through the thermal insulation or other places. And, it uses key "heat signatures" to identify when every section of the pipeline has transitioned from solid to liquid, allowing pumps to restart safely.

Using modelled pipeline heat loss simulations in conjunction with fibre optic DTS, dynamic, real-time models for flowing and solidified sulphur are available to safely and effectively manage the pipeline in either the optimisation of day-to-day operations or the challenges of complex phase changes (liquid to solid, or solid to liquid). The advanced analytics and predictive algorithms anticipate a problem before it happens.

The benefits are:
- electricity savings – optimised duty cycles for pipeline heating system and sulphur pumps;
- verification of insulation integrity;
- identification of any pipeline support/anchor problems;
- extended service life of pumps;
- reduced downtime and maintenance;
- greatly diminishes the likelihood of pipe over-pressurisation due to expanding sulphur during a re-melt;
- environmental responsibility;
- containment of environmental spill/emergency response;
- public relations – proactive posture and intervention (with agencies; public).

Table 1 shows example cost savings with flow assurance software for sulphur pipelines.

Comprimo® digital services

For over five decades, Comprimo® Sulfur Solutions has been licensing gas-treating and sulphur recovery units to the oil and gas industry. Many of these licensees have chosen to engage with Comprimo® in a so-called continuous services contract to stay in touch with Comprimo's process experts and get regular advice on how their units are doing and how they could maintain or optimise the performance. Also, in case of trouble shooting this provides a direct contact from the plant operation people to the Comprimo® experts. Traditionally, the communication related to the continued service of the licensed unit was done by sending across screenshots with DCS data, large data files and site visits for the Comprimo® experts to interact with operations.

With a newly developed inhouse data-analysis tool, DCS data stored in client's historian systems are periodically, typically once every week, compressed as three minutes average values and sent to a secured cloud-based data warehouse. The data is then automatically validated and processed and made available to the Comprimo® expert for interpretation of long- and short-term possible operational improvements. Key indicators are automatically calculated and trended, as well as, e.g. expected remaining catalyst life, energy optimisation, plugging etc. This can be done without requiring client data collection or communication or site presence. Also, in case of troubleshooting, very recent data will be available immediately and root causes for upsets can be identified. The built-in client interface of the tool, which has a DCS look and feel, also allows client operators to access the data and use it for training or process optimisation purposes.

The application uses data coming from the plant-owners' historian and gets stored in a protected cloud environment thus allowing fast and easy processing of large amounts of data. This set up prevents any direct connection to the DCS or risk of breach of any data security protocol. The high intensity of cloud-data storage still allows for very recent data to be available to the tool. Using this methodology, the data can be reviewed by Comprimo's experts with hardly any delay from the real-time data.

Feeding actual plant data into Comprimo's simulation software and comparing the simulation outcomes with actual plant behaviour will quickly reveal the causes for deviating plant performance. It also gives real time data to Comprimo's experts helping them in the continuous strive for optimising plant design. In case owners have multiple active gas-treating and/or sulphur recovery units, comparisons between the units can be made easily, this will provide input for owner's personnel on how to boost performance of all units to at least the level of their best performing unit.

The data oriented continued service contract increases the efficiency and accuracy of the continued services. The data availability provides ample opportunities for process optimisation and development, some of these as described in this article, some yet to discover.

Real-time optimisation and analytics via digitalisation in a sulphur circuit

Consulting and software services provider Helium Consulting recently designed and implemented a digitalisation project that enables modern day refiners to process higher sulphur content crude by debottlenecking their sulphur recovery units (SRUs). The solution is a cohesive ecosystem of enterprise connectivity, real-time analytics, operational excellence and Helium's industrial internet of things (IIoT) framework, which eases integration of business processes with digitalisation and control systems.

The primary objective of the solution is to optimise the sulphur recovery system and find the optimum operational parameters that enhance the performance while minimising cost and bottlenecks. This solution enhances the refinery's economic and environmental performance using a unified solution for the entire business process encompassing monitoring for the control of multiple processes operating multiple software applications on one platform – Helium's IIoT.

The integrated system (Fig. 10) provides several stakeholders in the refinery with a

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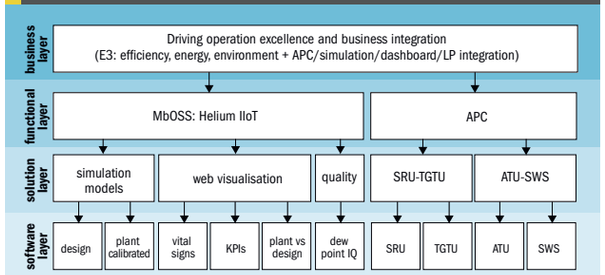
Fig. 10: **Integration of business processes with digitalisation and control systems**



Source: Helium

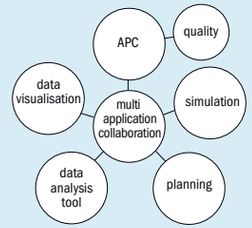
seamless stream of actionable insights, which enables the sulphur block as a whole to inspect the plant process, analyse for optimisation and early diagnosis of issues to prevent costly hidden upsets. The single window provides real-time actionable insights to optimise the process profitably, thus syncing numerous functions under one roof. The case described here highlights the approach and the key benefits of such an implementation for sulphur recovery unit in a refinery.

The following case study emphasises how a unified business process for sulphur systems can help to monitor track, control and optimise (through detailed analysis), expedited corrective actions and use of automated algorithms in real time. Multiple independent applications available in the plant are connected on one platform to provide an optimised solution. It enables easy, effective, and early (3E) inspection of the plant process to identify optimisation opportunities and to avoid expensive unscheduled and emergency shutdowns. Most importantly, it shows how integrated advanced process control, soft sensors, simulation and dashboarding technology can deliver real time benefits to refining and petrochemical customers.

Case study

A unified sulphur business process for operation and technology was implemented. In the first phase, adaptive process control technology was implemented for all the units in the sulphur recovery plant e.g. the amine treating unit (ATU), sour water stripper (SWS), sulphur recovery unit (SRU) and tail gas treating unit (TGTU). Helium Consulting was chosen as the technology implementation partner for optimisation, process simulation, integration of the plant historian and visualisation/analytics platform as a cohesive eco system for an integrated sulphur management system. Helium Consulting licensed its proprietary software for refinery IIOT to enable this implementation.

Fig. 11: **Digital manufacturing and advanced applications**



Source: Helium

This proprietary high-speed sulphur optimisation application integrates visualisation of key performance indicators (KPIs) and process analytics. The solution combines the deep domain knowledge of OT (operation technology) with IT (information technology) to offer unprecedented ability for online analysis.

The sulphur application intricately integrates multiple applications .The application connects to the plant/historian network and is integrated with multiple applications such as optimisation, simulation and other IT and OTs used in the plant.

All members from technical services, operations, optimisation group and the management team can access the system using the plant's local area network (LAN).

Unified solution implementation

The integrated application has been tested based on regular inputs from users and the plant's real-time performance. The dashboards have been implemented using the IIOT visualisation/analytics platform. Fig. 11. shows the architecture of the preliminary design undertaken.

Process benefits of sulphur management system

The collaborative digitalisation of multiple applications such as optimisation, simulation, soft sensors and historians have been the key factor to realise the refinery's vision. The sulphur application provides data integration with multiple applications, data validation, artificial intelligence/machine learning-based intelligent data analysis and KPI monitoring of a plant's operation using the visualisation dashboard. This help to convert a mountain of data into actionable information and translate the actionable information into decisions, leading to real day-to-day plant improvement.

The results are a typical set of recommendations indicating potential areas for enhancing energy and operational performance as well as closed loop interaction with plant operations. The open loop recommendations from the integrated solution are displayed in the dashboard as KPIs for each run. The integrated solution dashboard also indicates a comparison of actual plant performance versus design basis for each of the processes. The closed loop signals are integrated through a robust IIOT framework back to the control system. Users access this from the LAN and refer recommendations for appropriate operational actions.

Performance monitoring dashboard

The performance monitoring dashboard gives a real-time update on unmeasured plant parameters such as plant efficiency and production along with cost. A single window view displays overall plant performance as shown in Fig. 12.The real-time plant operating conditions can be monitored with colour difference showing plant status such as warning and shutdown. All the relevant information can be found from single source and the alert system for plant performance gives the user real-time information for plant monitoring.

Identification of suboptimal conditions

The SRU condensers condense and remove sulphur. The condenser performance is directly related to the sulphur recovery efficiency. The difference between the condenser outlet temperatures for the actual plant versus the potential temperature from the simulation model is shown in Fig. 13. Suboptimal condenser performance can be identified and further investigations can be carried out.

Fig. 12: **Plant performance monitoring screen**

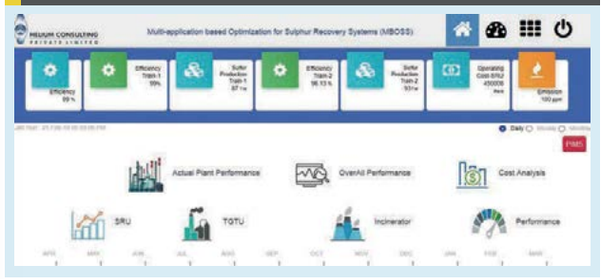
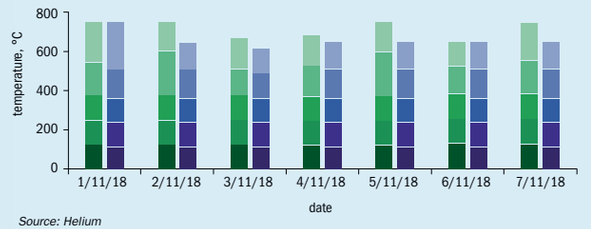


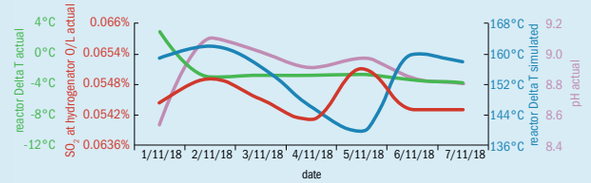
IMAGE: HELIUM

Fig. 13: **Condenser outlet temperature actual vs simulated**



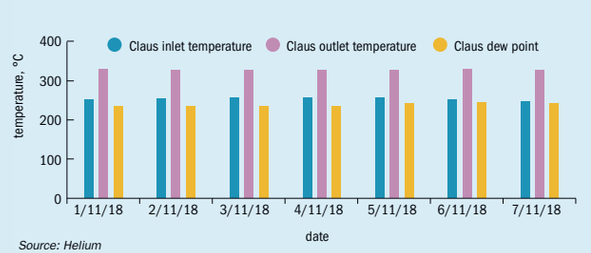
Source: Helium

Fig. 14: **SO_2 breakthrough with Delta T**



Source: Helium

Fig. 15: **Claus reactor performance**



Source: Helium

Optimisation using dew point calculations

The Claus reactor bed should be operated above the dew point of sulphur to avoid liquid sulphur from physically deactivating the catalyst. The dew point inferential created using data from the sulphur recovery simulation model is integrated with the optimisation application to avoid catalyst deactivation. The inferential developed requires regression against reference dew point values, which are derived using a sulphur recovery simulation application to control and optimise the Claus reactor process.

Root cause analysis

SO_2 breakthrough in the TGTU unit leads to higher emissions at the stack. In addition, SO_2 breakthrough from the hydrogen reactor could lead to elemental sulphur plugging in various equipment items such as quench column piping, column internals and can eventually lead to the unit shutdown. Fig. 14 shows SO_2 breakthrough in the unit. Early information of SO_2 breakthrough helps the operator to take corrective action.

Claus reactor performance

The higher temperature in the first Claus reactor helps to hydrolyse COS and CS_2. The SO_2 in stack emissions can be directly related to this temperature, which may not show up in the TGTU outlet. Fig. 15 shows the inlet temperature and dew point temperature of the Claus reactor.

Planning model accuracy

The planning model accuracy increased with the collaborative real-time simulation system, which acts as a guide to select accurate crude for the refinery.

In summary, the cross-domain collaboration support for all the functional teams helps to manage the operational decision-making lifecycle, to facilitate corrective actions and to sustain best practices and operational knowledge in the overall refining, petrochemical and gas processing process. The solution is equally applicable for driving improvements in other process units of refining, petrochemical and gas processing process value chain.

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Outotec digitalisation to enhance operations

Outotec, a technology provider in the mining and metals processing industry provides different digital tools to support operational needs.

PORS system

Outotec's PORS system (plant operability reliability and safety system) is an advisory tool focused on different safety aspects and designed to support operations, e.g. to detect malfunctions in the sulphuric acid plant. The system is a virtual process expert, monitoring the acid plant and providing assistance to operators. PORS assesses the plant's DCS system data and uses simulation models for the sulphuric acid plant. The results of these models are compared with reality in the so-called gap-analysis. Mismatch between reality and simulation are analysed and potentially hazardous situations are detected. Fig. 16 shows an example case of PORS being used for an acid cooler. The heat and mass balances are calculated and compared with actual figures, in addition a trend of the calculated heat transfer coefficient is also possible. The result is compared with historical data, so that changes can be detected, and operators can be warned. The PORS system enhances situation awareness of the operating personnel and improves the plant safety.

Pretium Roaster Optimizer

The newly introduced Pretium Roaster Optimizer supports optimisation of different operating parameters of the roaster and associated process operations, i.e. the pyrite roaster, gas cleaning and sulphuric acid plant

In a pyrite processing plant, the oxidation of iron sulphide leads to iron oxide and sulphur dioxide loaded off-gas, which is treated in a sulphuric acid plant to produce saleable sulphuric acid product. The main components of such a plant consists of a fluidised bed roaster, a gas cleaning plant and a sulphuric acid plant. In most cases, heat recovery from the highly exothermic reaction plays an important role for the economics of the plant operation. The Roaster Optimizer allows automated monitoring and control of various parameters, precise tracking of set points as well as fully automated load changes.

Typically, fluidised bed roaster plants are operated by human operators and supported by classic single-input single-output control loops. As an example, the roaster temperature can be controlled by water injection into the oven – increase of water flow to cool down and reduction of water flow to increase the temperature. Many more examples can be given in process roasting, gas cleaning and acid production. However, these numerous process parameters are monitored by the operating personnel who can easily miss important information or make decisions, which have a negative effect on other parts of the plant. Furthermore, human operators tend not to carry out operational actions if the plant is running at a high level. Thus, the plant operation may be stable, but it is not reaching the maximum possible level with the requested product qualities.

Fig. 16: **PORS system at the example of the acid cooler**

Source: Outotec

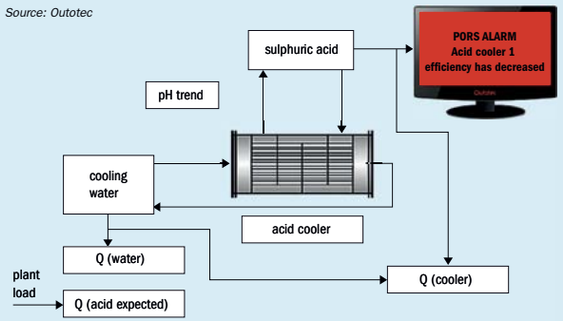
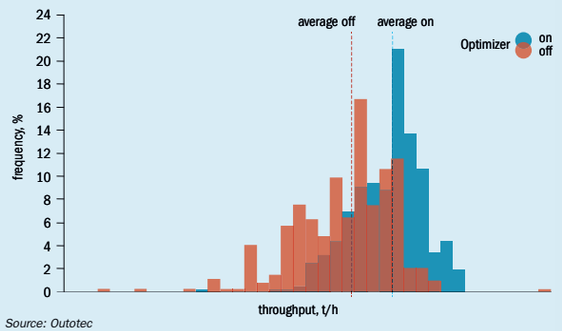


Fig. 17: **Feed rate with and without the Outotec Roaster Optimizer**



Source: Outotec

To overcome these operational disadvantages, Outotec has developed the Pretium Roaster Optimizer, a digital solution to further automate the operation of roasting, gas cleaning and acid plants. The Roaster Optimizer focuses, as the name suggests, mainly on the operation of the roaster unit which has an effect on the majority of processes throughout the complete process chain. The system monitors and controls various process variables in parallel. It keeps certain process variables within limits and guarantees precise tracking of the parameters relevant for product quality such as bed temperature and stoichiometry.

The chemical reaction in the example of pyrite roasting is:

$$2FeS_2 + 5½O_2(g) \rightarrow Fe_2O_3 + 4SO_2(g) \quad (1)$$

Depending on the feed material stream and the goal to recover certain metals, such as cobalt, copper, silver and gold, the temperature operating window for the roaster can be quite narrow. Thus, precise process control is required. Precise tracking of a narrow temperature window can create a challenge for the operators and provides an opportunity for the introduction of digitalisation tools such as the Roaster Optimizer. Precise tracking of the optimum process window allows the process plant to be operated very close to the theoretical limits.

With the Pretium Roaster Optimizer, operating companies have a digital operational support system, focussing on the roaster operation, at hand. In recent cases, the systems have been extended to respective upstream and downstream plant units: the Roaster Optimizer encompasses variables for gas cleaning and the acid plant and the PORS system extends to the roaster unit and gas cleaning

These systems allow very easy and reliable use of the plant at highest capacity. Process limitations are taken care of automatically, without any need for operator interaction. The recent extensions of the digital solution with new and additional variables, covering several plant sections, further improves the handling of the combined plant comprising the roaster, gas cleaning and sulphuric acid plant. Effects, which are not restricted to a single process unit are now handled more efficiently. Thus, the reaction times of effects on multiple plant units are shortened by using one comprehensive digital solution. As a result of the simplified process operation, a production rate increase of up to 5% can be observed. Fig. 17 shows a comparison of feed rate with and without the Roaster Optimizer.

Development of the digital system was focussed strongly on simplified operation while being robust against possible maloperation. The system is also used during load changes. It allows ramp-up and ramp-down procedures of the pyrite feed rate to the roaster between minimum and maximum plant load. Thus, the sulphuric acid plant is automatically ramped from 40% design load up to 105% design load and back, if required. During such ramp-up and ramp-down procedures, the before mentioned limitations and control features are maintained. It can be said, that the pyrite plant – roaster, gas cleaning plant and sulphuric acid plant – is operated with the Roaster Optimizer solely by clicking one button and setting a target production rate.

To date, the application of digital tools has yielded positive results and Outotec plans to expand the use of digital tools to other operational KPIs and industries (e.g. copper and zinc applications) to further enhance operations, improve plant reliability and increase productivity.

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Fax: +44 (0)20 7793 2577
Web: www.bcinsight.com
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Editor: RICHARD HANDS
richard.hands@bcinsight.com

Technical Editor: LISA CONNOCK
lisa.connock@bcinsight.com

Contributor: MEENA CHAUHAN
meena.chauhan@argusmedia.com

Publishing Director: TINA FIRMAN
tina.firman@bcinsight.com

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