Number 385

November | December 2019

SULPHUR

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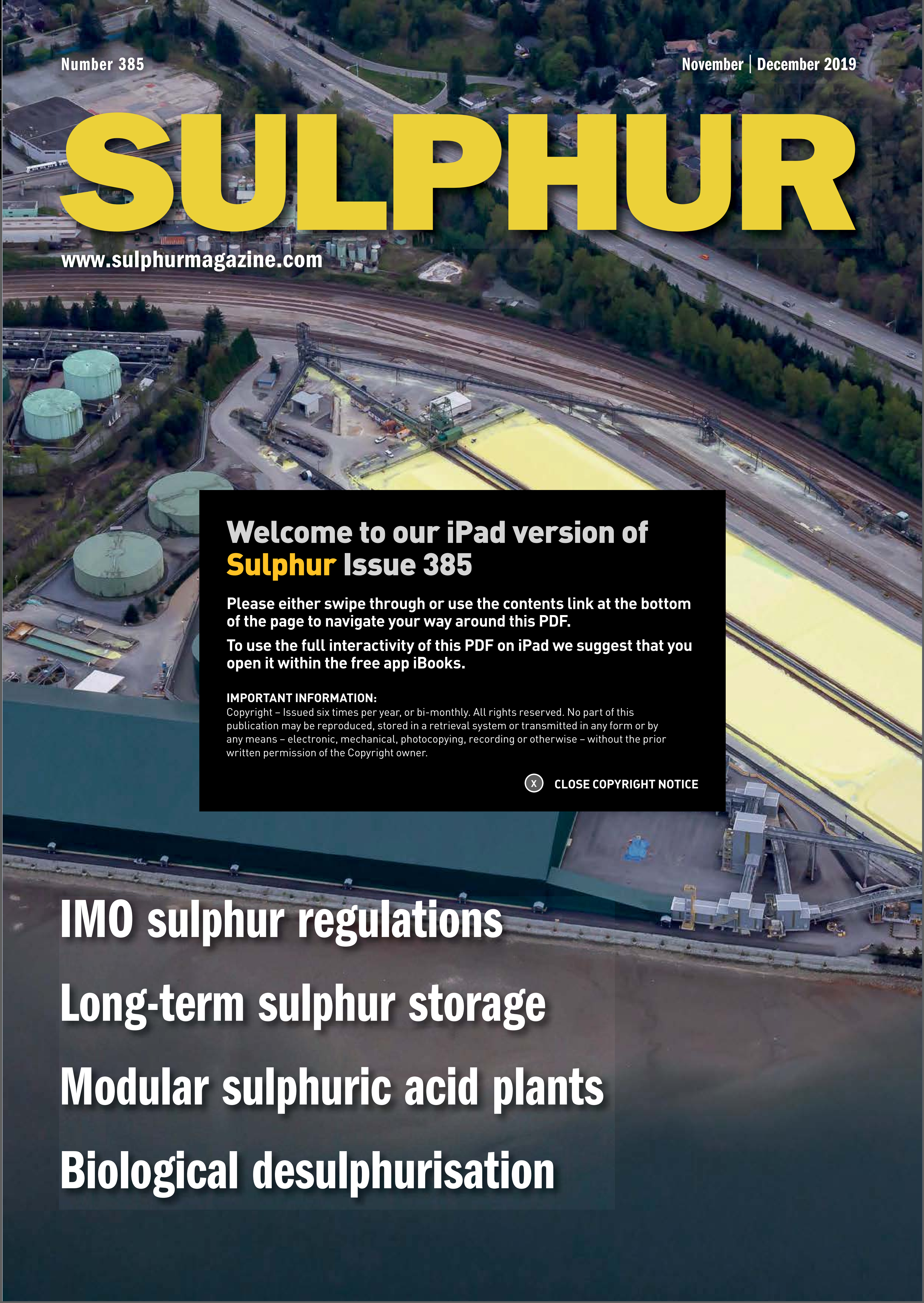

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Cover: *Aerial view of sulphur in Port Moody, Vancouver, Canada. iStockPhoto.com/edb3_16*

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Modular acid plant

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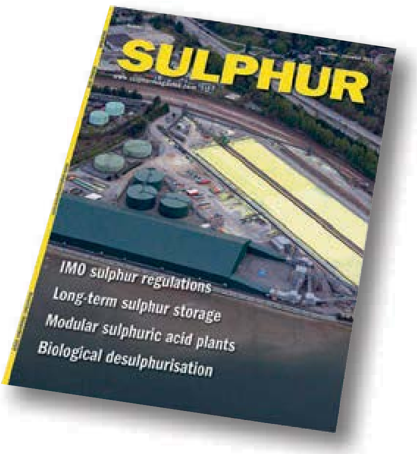
REGULARS

Déjà vu all over again?



> **It is not just sulphur which finds itself in oversupply, with falling prices.**

Sulphur prices have been dropping steadily this year, and have fallen below $60/t in most major markets. These are some of the lowest prices seen since 2009, in the wake of the global financial crash. For the sulphur industry, which saw a long period of oversupply during the 1990s, when prices were at similar levels or even lower, it might feel a little bit like – to quote US baseball legend and source of malapropisms Yogi Berra – "déjà vu all over again". But it is not just sulphur which finds itself in oversupply, with falling prices. Many commodity markets are in a similar situation. Natural gas prices are at their lowest levels for 10 years. Copper and steel prices have been falling all year, and oil prices have begun to follow them.

Much of the reason for this global commodities slump can be attributed to China and the slowing Chinese economy. Chinese GDP growth fell to 6.0% in 3Q 2019, its lowest level for 30 years, and that's just the official figure – a study in March 2019 indicated that Chinese GDP figures were overstated by 2% per year from 2008 to 2016, and there are persistent rumours that the current figures may be just as unreliable due to pressure on local officials to meet government targets. The figure of 6.0% is particularly suspicious given that it is the government's official target floor for growth.

The reasons for this are manifold – the ongoing trade dispute with the US is certainly not helping matters, but more than that, the country is dealing with huge overcapacity in many industries, a massive overhang of public and private debt, and most intractable of all, changing Chinese demographics as a result of decades of the 'one child' policy, which is rapidly increasing the number of retirees at the same time that fewer young people are entering the workforce. It is a similar 'demographic cliff' that Japan faced in the 1990s, leading to that country's so-called "lost decade" of deflation and stagnation, and there are fears that China could find itself in a similar position. China's median age will soon overtake that of the US. Consumer confidence, increasingly important for an economy that is trying to move from an industrial to a consumer-based one, has been hit by overcapacity in the housing market and falling house prices, while the Chinese government is reluctant to stimulate buying further by piling more debt into an already over-indebted economy. Investment has reached diminishing returns – there are no new roads, railways and factories that China needs to build at the moment, aside from a replacement of older, less efficient capacity.

On the sulphur front, China is buying less. Port stocks are at historically high levels, reaching 2.3 million tonnes in mid-September, well above the average figure of around 1.5 million tonnes that they stood at for most of 2018. Sulphuric acid prices have been falling all year, especially for smelter acid. As more Chinese smelter capacity comes on-stream, it is becoming more difficult for smelters to offload their acid. Those that can are selling onto the international market, helping to bring down acid prices globally, otherwise they are displacing the need for sulphur burning acid capacity to buy new sulphur.

The market dip in 2009 caused by the global financial crash followed a speculative bubble that saw Vancouver sulphur prices reach an incredible $800/t before slumping to $30/t within months. But it was short lived, at least in part because at the time the Chinese economy was still growing by 10-11% year on year, and needed more copper, more steel, more phosphates, and helped drive demand for sulphuric acid and sulphur. This time, however, the price slump looks to be more structural and may take longer to clear. It comes at the same time that refiners are having to extract more sulphur to meet the new IMO regulations, and large sour gas projects continue to come on-stream in the Middle East and Central Asia, while phosphate demand is subdued.

Richard Hands, Editor

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Price trends

MARKET INSIGHT

Claira Lloyd, Sulphur Editor and Sulphur Fertilizers Team Leader, Argus Media, assesses price trends and the market outlook for sulphur.

SULPHUR

The market has now surpassed its one-year anniversary of falling spot prices and still the market remains bearish. Fourth quarter contracts, which often help with market sentiment and can provide price guidance, have all settled down on 3Q prices, and in many instances at the lowest level since contracts were introduced. But this time around they have brought with them some unusual outcomes which will change some of the market dynamics for the rest of this year.

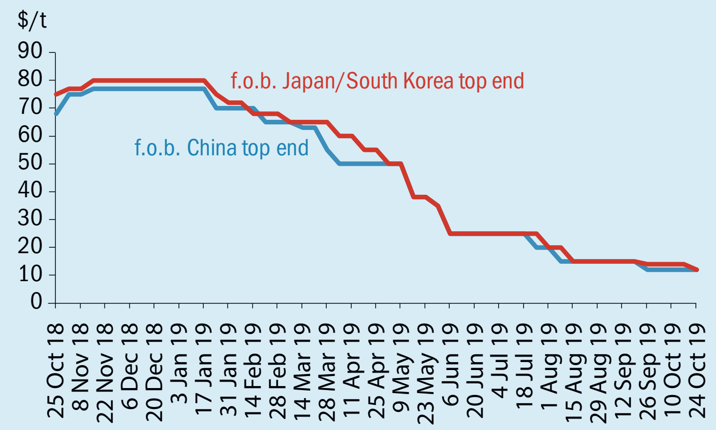
Abu Dhabi state-owned sulphur supplier Adnoc has not agreed any contract settlements with Moroccan fertilizer producer OCP, Tunisian fertilizer producer GCT or agreed tonnes to deliver to US-based fertilizer producer Mosaic's Brazil operations. This has left the producer with upwards of 750,000t of sulphur to place elsewhere. In Brazil, Mosaic is understood to not be securing any product under contract at all for the quarter and will rely on the spot market instead. In West Europe, where contracts for molten sulphur are concluded on a c.fr Benelux basis, they have been settled at a drop of $25/t on the 3Q range. West European contract prices have been settling flat for a year and this drop is most welcome to buyers, which have struggled to remain competitive, particularly against Asian companies, who have benefited from sulphur prices below $100/t c.fr for some time. But a question mark has now been placed over security of supply across the rest of this year because of the price drop. Indeed, the European molten market is currently being described as more balanced-to-tight, rather than just tight as it has been for much of this year. Yet, the improvement in the supply/demand balance can be linked to sulphur producers across most of this year looking to markets outside of western Europe, such as Spain and the US, to help cover their supply deficit. Now that prices have dropped by $25/t the costs of covering such journeys may not be possible. So, it could now be up to consumers to step in to the market in search of the product they need, bringing more liquidity and a new dynamic to the molten sulphur market in the coming months.

Now looking at the spot market. Granular sulphur prices in China, the world's biggest sulphur buying market, are under $70/t c.fr for the first time since November 2009, and there is still no hope of price recovery. The continually poor phosphate market sentiment remains the number one influential factor on the sulphur market, especially as China's DAP fob price has reached a three year low of $310/t. And as a result, China's key phosphate producers have extended the 40% production cuts for the rest of the year, which will further hamper their demand for sulphur. But it's still not only the phosphate market which is hitting the sulphur market, stocks at Chinese ports are still holding at 2.2-2.3 million tonnes with expectations of more growth, and the lack of 4Q contract conclusions between Adnoc and key west of Suez consumers has further bolstered the confidence of Chinese buyers that the market is long and therefore prices have plenty more room to fall. Now, the only demand in the market is for end of year loading vessels and buyer price ideas are sitting at around $60/t c.fr.

For the world's biggest supply market, the Middle East, whilst contracts were not settled by Adnoc with all end-users, it is understood that the company has placed the product in the hands of other offtakers, such as traders, and is now sold out of the rest of the year. Other suppliers also seem to be comfortable with Qatari state-owned marketer Muntajat cancelling its monthly spot tender for a November and December shipment, having allocated the tonnes elsewhere and Kuwaiti sulphur producer KPC has placed its five quarterly cargoes under contract. Yet, whilst producers are not under any pressure, there is no expectation that this will provide buoyancy to the Middle East spot market as the sulphur has already been allocated no doubt covering plenty of buy-side party demand for the rest of the year.

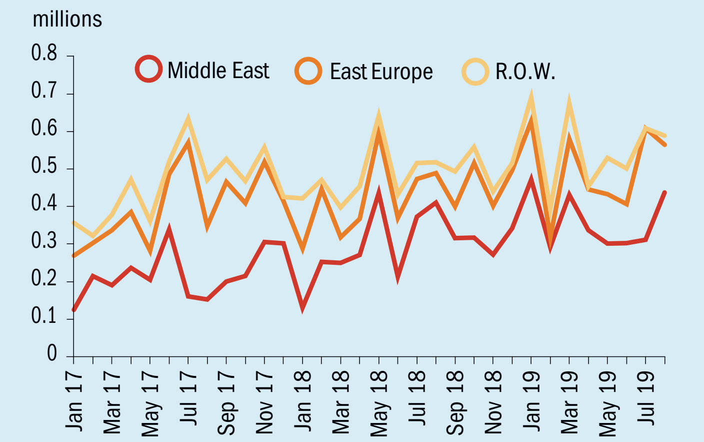
In North Africa, speculation remains that without Adnoc's sulphur, Moroccan and Tunisian consumers will be stepping in to the spot market for significant volumes. So far this has not seemed to be the case as Russian sulphur supplier GazpromExport will unusually be supplying upwards of 300,000t to the regional market ahead of the closure of the Volga Don river system for the winter and there is also around 200,000t of Baltic Sea loading sulphur headed for the region. East European product had not been getting to the North African market with much frequency in 2017-2018 because of logistical limitations, especially Volga Don river barge

Fig. 1: **Sulphuric acid spot market pricing, $/t**



Source: Argus Media

Fig. 2: **Morrocan imports**



Source: Argus Media

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capacity. But this year, that has changed and should help fill the gap.

Indian buyers have very recently covered their demand with fertilizer producers Paradeep Phosphate and CIL securing spot cargoes. Their purchases brought India's c.fr price under $70/t, allowing this key buying market to join others in the $60s/t c.fr club. Indian demand is not likely to return from the key east coast consumers until late November, and small buyers are still absent from the market with the start of the sugar season delayed. The heavy rains in central, western and parts of southern India have resulted in a delay in harvesting and therefore crushing is not to start until mid-November, a month's delay.

In Brazil, despite the lack of 4Q supply contracts, consumer Mosaic has secured spot market sulphur in the mid-$60s/t c.fr, the lowest price ever achieved in Brazil, and is now looking for possibly only one cargo to cover the rest of the quarter. Consumer CMOC has already secured the rest of its 2019 requirements and will next seek 2020 deliveries. But a new significant buyer is expected to come to the market before the year ends, and that is Norway-based fertilizer producer Yara. Since acquiring the remaining minority stakes in various Galvani phosphate production assets in the country, and with the impending start-up of the Serra do Solitre project in Minas Gerias, the company now has a total demand of 500,000 t/a for Brazilian operations which will likely see them step in before the year end for a cargo.

SULPHURIC ACID

Sulphuric acid prices have been experiencing a period of firm sentiment in some regions, much in contrast to the sulphur market, but despite this, prices have been remaining overall range bound. Stability is expected to persist in the coming month but there is a noted improvement in sentiment. But, despite this stability and some prompt demand which is always welcome, the market will be tested if major maintenance work is completed on schedule in the fourth quarter.

In Latin America, Chilean spot prices have increased by around 4% recently but now spot activity is limited with consumers well covered and attention being mainly focused on annual contract negotiations. Contracts are not expected to settle until early-November at the earliest. Also, the current civil unrest in Chile will potentially impact demand in the near term. Brazilian spot prices have picked up of late with an uptick in buying interest, but no stability is expected to reign with buyers largely indicating that they are covered and comfortable. June – 12 October, 299,681t of acid has been discharged at Brazilian ports but overall, Brazil's imports January-July were down by 26% which does suggest that there could be some more buying to come.

US vessel import prices have been holding steady once again and have in fact been trending flat on the midpoint since 6 June. The market has remained fundamentally quiet which is keeping prices steady.

The northwest European spot market price range has seen a pickup of around 11% in prices over the last month. Multiple maintenance turnarounds have led to supply tightness in the region. These works at producing facilities are now pointing at a strong firm sentiment around fob export prices. Any product that is moving is towards the Americas under previously concluded contract and any discussion in the market now is focused on annual contract allocations agreements. Fourth-quarter contracts have already settled at a rollover from the third quarter at €79-90/t. The shutdowns in the region and steady demand has offset some of the previous softening in international markets, which buyers said should support a decrease.

In Asia, South Korean and Japanese export prices have softened marginally over the last month. Attention is now firmly focused on the year ahead and a slight firming in prices is expected for 2020 annual contract agreements. In China, the spot price has weakened slightly for deliveries to long-haul destinations. Market sentiment is however stabilising in the region, especially as the domestic market is giving some support on the demand side as well as with key producer Two Lions holding prolonged maintenance at the end of this year.

There is currently some demand in India from fertilizer producer FACT which is seeking a late-November delivery. Offers are in the low-$40s/t c.fr at present to the Indian market, holding top-end spot prices steady. The Indian market has been trending in the low-$40s/t c.fr on the top-end price point since mid-September.

Price indications

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

Cash equivalent	May	June	July	August	September
Sulphur, bulk ($/t)					
Adnoc monthly contract	105	102	79	n.a.	49
China c.fr spot	115	118	95	75	66
Liquid sulphur ($/t)					
Tampa f.o.b. contract	88	88	75	75	75
NW Europe c.fr	110	110	98	98	80
Sulphuric acid ($/t)					
US Gulf spot	95	95	95	95	75

Source: various

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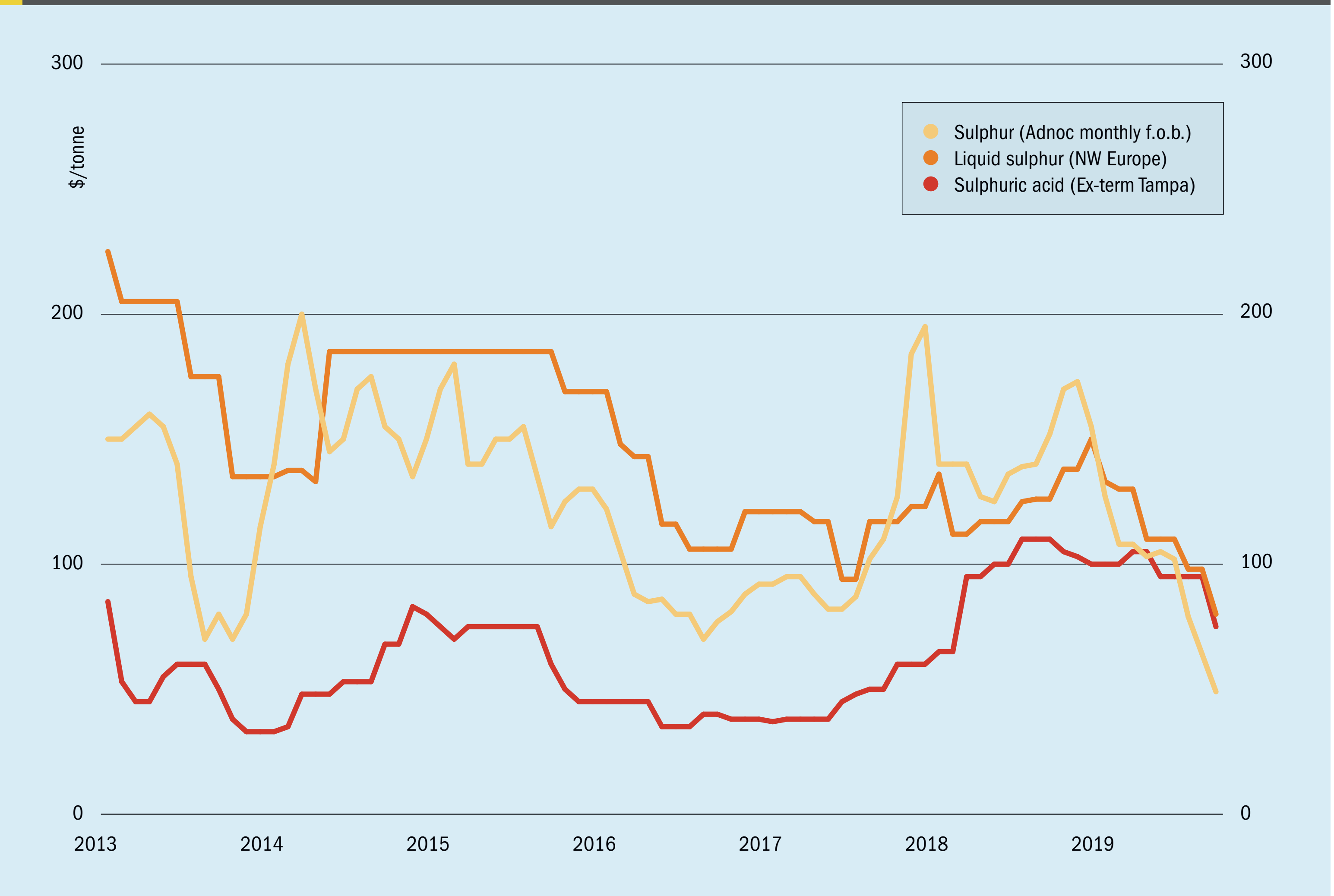
Market outlook

Historical price trends $/tonne



Source: BCInsight

SULPHUR

- **Outlook:** Prices are going to continue their flat-to-soft trajectory for the rest of 2019 and most likely until after the Chinese Lunar New Year holidays which start on 24-25 January. Market fundamentals on both the demand and supply side show no signs of changing to provide market support before buyers return in mid-February at the earliest. There could be some periods of stability in the market across the rest of this year, but this stability will not come because of a balanced market, but because of a complete lack of liquidity as end-users are in no hurry to step in to the market and traders in particular are covered with forward selling having been the key strategy for the most of this year in an attempt to cut losses and cover positions in such a bleak market.
- Implications of the IMO 2020 regulations to continue causing concerns in the freight market, especially with f.o.b. and c.fr prices so close. Some routes are already seeing elevated costs because of what has been called the 'war premium' on routes to and from the Middle East, and now additional premiums are coming in to play as vessel owners seek to buffer additional cost implications of the marine fuel legislation and fuel cost increases.
- Chinese port inventories are expected to grow, potentially reaching capacity of 2.6-2.8 million tonnes, as extra Middle East volumes are placed in the Chinese market and the Lunar New Year holidays curb liquidity on an ex-port basis.
- No support is expected to come from the phosphate market before the second quarter of 2020 at the earliest with measures to combat oversupply minimal except for China where DAP production cuts are to remain in place until at least the end of the year.

SULPHURIC ACID

- Stability and some improvement in sentiment is notable and sustainable for prompt loaders which is helping to provide support in the near term. But, weak macroeconomic signals in key markets, combined with low sulphur and phosphate prices are going to weigh on demand and could end up putting a cap on pricing for the rest of this year. But as long as maintenance periods remain in place the prompt loading markets should maintain a consistent pricing level.
- South East Asian producers will be reluctant to accept prices in the single digits on an fob basis as maintenance drives tightness on the producer side.
- The length to which the civil unrest persists in Chile along with the varying ongoing strike action could restrict demand from a key consuming market. Antofagasta's copper production has already been reduced by 5,000t because of the unrest.
- Annual contract settlements are to come to their final conclusions by mid-November and expectations are that they will conclude largely in line with current spot prices. This is likely to further cement the stability in the sulphuric acid market for the rest of the year if other fundamentals remain consistent also.

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IRAQ

Sulphur shipments begin from Badra

Gazprom Neft subsidiary Gazpromneft-Badra says that in September it shipped its first cargo of granulated sulphur from its Badra crude treatment plant in Iraq. The first shipment of 1,000 tonnes was delivered to Iraqi client Ard as Sakhlya via truck, and a 3,000 tonne shipment followed. The Badra oil field in eastern Iraq's Wasit province is estimated to hold 3 billion barrels of crude oil and is operated by Gazprom Neft, which also owns a 30% stake in the project in partnership with Korean Gas (22.5%), Petronas (15%), TPAO (7.5%) and the Iraqi Oil Exploration Company (25%). Oil production began in 2013 and totals 170,000 bbl/d.

Gapzrom says that the gas processing infrastructure that it has installed at the site has made it possible not just to diversify production, but also increase associated petroleum gas utilisation to 98%. Sulphur production capacity at the site totals 110,000 t/a, with a granulation capacity of 136,000 t/a at the 1.6 bcm per year gas processing plant at the Badra field. Gazprom Neft says that it has produced 72,000 tonnes of sulphur to date, now in storage, which is expected to be shipped to Iraqi customers as orders are received.

Vadim Yakovlev, first deputy CEO, Gazprom Neft, commented, "We have, in Badra, created a modern industrial complex, unique in the variety of its output, producing not only oil and gas but also granulated sulphur and electricity. Cutting-edge technological solutions have allowed us to monetise all hydrocarbons produced, as well as ensuring optimum environmental friendliness on this project."

UNITED STATES

New sulphur ship loader for Beaumont

Martin Operating Partnership has commissioned Bruks Siwertell to supply a new ship loader for its sulphur handling facility at Beaumont, Texas. Martin Operating Partnership, owned by Martin Midstream Partnership, handles various sulphur cargoes. Siwertell says that the new rail-travelling loader is ideal for terminals where space is at a premium, as it can fill every hold on a ship without requiring the vessel to move along its berth. It will be used for loading prilled sulphur into ship holds at a rated capacity of up to 1,200t/h.

The prilled sulphur can be stored and loaded in open air; however, minimising sulphur dust emissions was a key concern for the company, and the fully enclosed ship loadings conveyors, as well as its dust suppression systems, are designed to ensure environmental protection. The delivery will be a repeat order, with delivery scheduled for January 2020 to support Martin's expanding sulphur services in the US Gulf Coast region.

"There can be no greater endorsement than repeat business," said Ken Upchurch, vice president sales and marketing, Bruks Siwertell. "we are delighted to renew our strong 15-year business relationship with [Martin]. This trusted position, our proven technological capabilities and our commitment to deliver the loader within the space of nine months were all factors that secured the contract," he added.

Reusable sulphur recovery catalyst

Porocel has launched *EcoMax*™ Catalyst Renewal, a patent pending technology for reprocessing and reuse of sulphur recovery catalysts. The treatment removes contaminants from spent cobalt-molybdenum (CoMo) hydroprocessing catalysts, ultimately restoring activity to fresh catalyst levels. *EcoMax* catalysts may be employed in either conventional or low temperature tail gas treating units at a substantially lower cost than fresh CoMo catalyst. The catalysts maximise the refiner's return on investment and extends the service life of the catalyst. *EcoMax* Catalyst Renewal also reduces CO_2 emissions from catalyst manufacturing by more than 10,000 pounds per ton of catalyst replaced.

US refining capacity at record levels

The US Energy Information Administration (EIA) reports that, as of January 1st, 2019, US operable atmospheric crude oil distillation capacity was a record-high, at 18.8 million bbl/d. This is an increase of 1.1% since the beginning of 2018, according to EIA's annual Refinery Capacity Report. The previous record high of 18.6 million bbl/d was set at the beginning of 1981. US crude oil distillation capacity has increased in six of the past seven years.

SERBIA

Sulphur plant for tyre production

Chinese chemical giant Yanggu Huatai has announced that it will build a 20,000 t/a insoluble sulphur plant in Serbia. The investment is worth 30 million euros, according to Serbian government officials.

The plant will be located in Zrenjanin, northern Serbia, and will supply raw materials to a tyre factory belonging to Chinese car parts manufacturer Linglong, currently under construction and expected to start production in 2021. Insoluble sulphur is a polymeric form of sulphur mainly used as a vulcanisation accelerator and agent in the rubber industry. It allows a more solid adhesion of the rubber, prevents the rubber from breaking apart and improves resistance to heat and tyre wear.

According to a memorandum signed by the Chinese company and the Serbian government, the plant will be operational within the next three years.

UNITED KINGDOM

Fawley to add new diesel hydrotreater

Local authorities have approved an £800 million ($1.0 billion) expansion of ExxonMobil's Fawley refinery near Southampton. The expansion will increase production of low-sulphur diesel by 45% or about 38,000 bbl/d, helping reduce the UK's reliance in imports of diesel. Construction work is due to begin by the end of 2019, and will include a new hydrotreater and hydrogen plant. Detailed planning and design work has been carried out by Wood Group.

OMAN

Sulphur fertilizer trial to combat salinity

Oman Shell has signed a contract with Sultan Qaboos University (SQU) to conduct research aiming to find solutions to address soil salinity across Oman's Al Batinah region. Soil salinity is increasing in Al Batinah due to seawater intrusion, as well as high temperatures and low rainfall. Shell will provide samples of *Special-S*, a sulphur fertiliser produced using Shell Thiogro technology for use by the SQU research team. This product will be evaluated to determine its effectiveness in remediating saline soils through soil acidification.

Dr Daniel Blackburn, Project Leader from the Department of Soils, Water and Agricultural Engineering of Sultan Qaboos

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University said, "The salt contamination of agriculture soils on the Al Batinah region has been a real agricultural challenge, reducing farm yields and profitability, and in extreme cases, forcing farmers to abandon their lands. Our collaboration with Oman Shell represents a fantastic public-private partnership directed at community wellbeing, as we believe that the use of *Special-S* will provide continuous sulphur and nitrogen nutrition to crops. This product will aid directly on the reclamation programs of salt-affected soils, helping to leach the excess of sodium salts, whilst decreasing soil alkalinity and improving plant nutrition. With this technology, we hope to give a substantial contribution to the sustainable management of Omani soils and to the country's food security."

Walid Hadi, country chairman – Oman Shell said, "Soil salinity is an increasing concern for the Al Batinah region. We are working together with SQU to conduct critical research that we hope will be a big contributor to a productive and sustainable agricultural sector." He added, "We are eager to work with the brilliant minds in SQU to meet this real-life challenge facing this industry."

The research will run from November 2019 to April 2020 at the Agricultural Experiment Station of Sultan Qaboos University before a final technical report is produced with key findings and next steps.

Saipem awards sulphur storage subcontract

Oman's Galfar Engineering and Contracting has won a $2.7 million subcontract from Italian oil and gas contractor Saipem to deliver structural steel erection work for petcoke and sulphur storage shelters at Duqm refinery. The refinery is a $7 billion integrated complex being developed through a partnership between Oman Oil Co and Kuwait Petroleum International in Special Economic Zone in Duqm (Sezad). The subcontract forms part of Saipem's Package 3 engineering, procurement and construction (EPC) contract for offsite facilities at Duqm. Work on the project will commence in November 2019 and is expected to be completed in July 2020. Upon completion in 2022, Duqm refinery is expected to process 230,000 bbl/d of crude oil, primarily producing diesel, jet fuel, naphtha, and liquefied petroleum gas.

IRAN

Contract signed for Balal sour gas field

Iran's Petropars has signed a contract with the Pars Oil and Gas Company (POGC) to develop the offshore Balal sour gas field in the Gulf. The $440 million contract was signed in the presence of Iran's Oil Minister Bijan Namdar Zanganeh. Petropars aims to produce 14 million m^3/d (500 million scf/d) of sour gas once start-up is achieved in 2022. The gas will be transferred to the offshore platform of Phase 12 of the South Pars Gas Field and, after processing, will be piped to the onshore refinery via an undersea pipeline. According to the contract, POGC, a subsidiary of the National Iranian Oil Company, will also carry out reservoir studies.

Shell's Caroline gas plant, Alberta.

PHOTO: SHELL CANADA

CANADA

Sour gas processing plant commissioned

Tidewater Midstream and Infrastructure Ltd says that it has completed commissioning and start-up of the Pipestone Montney sour gas processing complex. The Pipestone plant is designed to process approximately 100 million scf/d of sour gas and includes an acid gas injection well, salt water disposal well, and pipelines that directly connect to Tidewater's Pipestone Gas Storage Facility. It also has tie-ins to both the Alliance and TC Energy pipeline networks. Sour gas processing began on September 15th, according to the company, and it is processing 30 million scf/d during its initial start-up phase. Tidewater says that it expects to reach full or near full capacity of 100 million scf/d by the end of 2019.

Shell sells Caroline gas plant

Shell Canada Energy says that it has finalised the C$190 million sale of its huge Caroline sour gas plant as well as other assets in western Alberta to Pieridae Energy Ltd. Ikkuma Resources Corp., a subsidiary of Pieridae, will operate the assets including three sour gas plants; Waterton, Jumping Pound and Caroline, as well as the gas fields which feed them, and 40% of the Shantz Sulphur Forming facility – Shell will retain the remaining 60% share, although Ikkuma will take over operation of Shantz. Shantz is tied to the Caroline gas facility through an underground pipeline. All site-based Shell employees and some Calgary-based Shell employees who predominantly support the assets will be retained, the company said. Shell will retain its sulphur, natural gas liquids and condensate sales and marketing businesses.

"Shell has built a strong foundation of reliable, competitive and safe sour gas operations in Alberta over many decades. I want to thank the many Shell employees and contractors who contributed to the success of these assets," said Shell Canada president Michael Crothers.

UNITED ARAB EMIRATES

Lukoil takes 5% stake in Ghasha

The Abu Dhabi National Oil Company (Adnoc) has given Russia's Lukoil a 5% stake in the Ghasha sour gas concession, comprising the Hail, Ghasha, Dalma and other offshore sour gas fields. Adnoc, Lukoil, and the Russian Direct Investment Fund (RDIF) have also signed a framework agreement to explore potential future cooperation in relation to the Ghasha concession. The agreement was witnessed by Sheikh Mohamed bin Zayed Al Nahyan, Crown Prince of Abu, and Vladimir Putin, president of the Russian Federation, on a state visit to the UAE. Lukoil will invest an initial $190 million as a signing fee for the concession. Adnoc retains a majority stake in Ghasha, in which it is also partnered by Eni, Wintershall Dea, and OMV.

Ghasha is expected to produce over 1.5 billion scf/d of natural gas by 2025. The natural gas will be used to generate electricity for more than two million homes. More than 120,000 bbl/d of oil and condensates are also expected to be produced. In addition to developing the Ghasha concession area, Adnoc plans to increase production from its Shah sour gas field from about 1.3 to 1.5 billion scf/d of natural gas. The company also plans to develop unconventional gas reserves, as well as new natural gas accumulations. ■

Sulphuric Acid News

WORLD

Uranium demand projections revised upwards

The World Nuclear Association's projections for nuclear generating capacity growth have been revised upwards for the first time in eight years, following the introduction of more favourable policies in a number of countries. In France, the country's energy policy has been modified, delaying the planned reduction of nuclear power in the share of its electricity mix and allowing operating lifetime extensions of existing reactors beyond 40 years. In the USA, state legislatures are starting to pass measures that support the continued operation of reactors, recognising the valuable role of nuclear in providing low-carbon electricity. At the same time, the process of granting a second operating licence extension for US nuclear reactors has begun, allowing reactors to operate for 80 years. Both China and India have extensive nuclear expansion programmes and the prospects for new reactors in many countries have improved with several newcomer countries such as Turkey, Bangladesh and Egypt launching construction projects and several more, including Uzbekistan, Kazakhstan and Poland, demonstrating a clear interest in developing nuclear programmes.

The WNA's upper and reference scenarios now show global nuclear power capacities growing over the period to 2040 at a faster rate than at any time since 1990, increasing mainly due to extensive reactor building programmes in China, India and other countries in Asia. While projected growth in the reference scenario is moderate, with capacity growing to 569 GWe by 2040, in the upper scenario the present level of nuclear capacity is expected to almost double to 776 GWe. For the lower scenario, nuclear capacity essentially maintains its current level over the forecast period at 402 GWe.

The uranium market has been characterised by oversupply in recent years, which has led to a sizeable reduction in uranium production levels at existing mines and a sharp decrease in investment in the development of new and existing mines. The three scenarios of uranium supply show that the capacity of all presently-known mining projects (current and idled mines, projects under development, planned or prospective) should be at least doubled by the end of the forecast period, and the need for new primary uranium supply becomes even more pressing as a number of older mines are projected to be depleted in the second decade. The net effect is likely to be a significant increase in sulphuric acid demand for uranium leaching over the next two decades. ■

INDONESIA

Indonesia brings forward ore export ban by two years

Indonesia has decided to bring forward a ban on exports of nickel ore by two years. Originally slated to begin on January 1st 2022, the ban will now take place as soon as January 1st 2020. Indonesia said it had expedited the ban to reserve ore supplies for its rapidly expanding nickel smelting sector, producing nickel pig iron (NPI), stainless steel and electric vehicle battery nickel. The ban was first introduced in 2014 to try and force development of a downstream nickel processing industry in Indonesia, based on its extensive deposits of nickel, rather than seeing its ore go to feed production in China and elsewhere. It was relaxed under a quota system in 2017. The restrictions have had the desired effect in developing a domestic nickel industry. From nearly zero in 2014, Indonesia's NPI output climbed to 261,000 t/a in 2018 and could reach 530,000 t/a in 2020. It currently has a base of 11 working smelters with an input capacity of 24 million t/a of ore, and plans to add 25 more smelting units.

Now Indonesia is also hoping to become a hub for electric vehicle battery production. This requires higher grade nickel production, and has led to a large-scale revival of interest in high pressure acid leach (HPAL) production, consuming large volumes of sulphuric acid. Tsingshan and its partners have two battery nickel projects with combined capacity of 110,000 tonnes in nickel content and aimed to start production from end 2020, pending permits from the authority and financing, one of which will be a 50,000 t/a HPAL plant at Tsingshan's industrial park in Morowali, on the Indonesian island of Sulawesi. PT Vale Indonesia and Sumitomo Metal Mining Co Ltd are also conducting a feasibility study of a 40,000 t/a battery nickel project based on HPAL, while Indonesia's Harita Group and China's Ningbo Lygend is planning another battery nickel plant.

The ore export ban has already led to a surge in nickel prices, which are expect to reach $20,000/tonne over the coming months. There is a predicted nickel shortfall of 51,000 tonnes in 2020 and a deficit of 127,000 tonnes in 2021.

MADAGASCAR

Ambatovy plans shutdown in November

Nickel and cobalt producer Ambatovy says that it will close its high pressure acid leach (HPAL) plant for planned maintenance during November. The plant, 11km south of the port of Toamasina in eastern Madagascar, will shut for two weeks in November for the first part of the planned maintenance, followed by a partial shutdown for the second stage of the shutdown, which will also last for two weeks. Ambatovy produced 35,473 t/a of nickel in 2017, against a theoretical capacity of 60,000 t/a.

Ambatovy, a joint venture between Sherritt International, Sumitomo Corp and Korea Resources Corporation, has two sulphur burning acid plants with the capacity to consume around 500,000 t/a of sulphur. Ambatovy was reportedly looking to secure three cargoes of sulphur to cover its fourth-quarter demand of around 150,000 tonnes, but may now defer one cargo to early 2020 because of the maintenance works.

CANADA

Acid plant up and running at Trail smelter

Teck Trail Operations says that its new $174 million No.2 acid plant is now fully in service at the Trail zinc-lead smelter in British Columbia. The plant has been operating since 2Q 2019, but in September successfully completed its run-in period. With a capacity of 1,040 t/d, it is a duplicate of the No.1 acid plant at the side, which came on-stream in 2014. The two modern plants have replaced several older 1970s-era plants, and reduce SO_2 emissions from the smelter complex.

In a press statement, Thompson Hickey, General Manager, Trail Operations, said; "This investment supports our ongoing focus on sustainability and the long-term viability of our operation. Using the best available technology, the new plant will enhance productivity and operational efficiency here at Trail Operations, reducing downtime and maintenance costs." The statement added: "Our employees and contractor partners have exemplified safety as a core value on the project, which was completed with zero lost time injuries."

Sulphuric acid from Trail is sent to Teck's Warfield site for use in ammonium sulphate and other fertilizer production, or sold on the open market for other industrial applications.

CHILE

Coro announces progress with copper leach project

Vancouver-based Coro Mining Corp. says that it has had positive results from its phase II drilling programme at the Marimaca project in Chile's Antofagasta region of the northern coastal copper belt. The results of 385 test bores show that the copper deposit now measures around 700 x 1,400 metres and is 100-300 metres thick with multiple high grade zones. A revised preliminary economic assessment (PEA) based on the new findings will be completed in 1Q 2020, but statements from company executives indicate that the initial assessment of production of 10,000 t/a of copper cathode could be revised to as high as 70,000 t/a once fully operational. The company is now planning a third phase of drilling to further characterise the deposit.

It is one of the few new copper discoveries in Chile, and is expected to operate as an open pit mine with heap leaching using sulphuric acid and solvent extraction/electrowinning (SX/EW), potentially consuming large volumes of acid.

GERMANY

Lanxess celebrates 125 years of acid production

German speciality chemicals company Lanxess has marked 125 years of sulphuric acid production at its facility at Leverkusen. Production began in 1894, but over the years the plant has been continually modernised to its present capacity of 220,000 t/a. A new production line, which will increase the capacity of chemically pure sulfuric acid, and a laboratory building with a state-of-the-art infrastructure will be commissioned in the coming weeks.

"The sulphuric acid plant is the heart of Lanxess' inorganic production network in Leverkusen. Without this plant and its impressive history and state-of-the-art technology, Leverkusen would not be able to produce chemicals in the form in which it does today. And it is impressive how this facility with its workforce continues to develop," said Hubert Fink, member of the Lanxess AG Board of Management.

BRAZIL

Itafos launches new premium products at Arraias

Itafos has launched its new line of premium phosphate products at its Arraias site following the recent completion of initial production and sales of premium PK compound products as well as higher grade SSP. The new premium products are part of a programme to optimise Itafos Arraias' finished fertilizer production with a multi-product portfolio including higher grade SSP (21% phosphate), micronutrient enhanced SSP (19% and 21% phosphate) and premium PK compound products.

"Producing premium PK compound products and higher grade SSP and micronutrient enhanced SSP demonstrates our ability to repurpose Itafos Arraias to focus on higher netback products and improve our margin profile," said Dr. Mhamed Ibnabdeljalil, interim CEO of Itafos.

MOROCCO

OCP reports positive 1H results

Morocco's Office Cherifien de Phosphates (OCP) has reported sales growth of 4% for its results for the first half of 2019, in spite of what it describes as "severe market conditions". Sales revenues for January to June 2019 were 27.6 billion dinars ($2.86 billion), with significantly higher output, as well as an increase in phosphoric acid prices, mitigating lower output in the rock and fertilizers sectors. This helped the company maintain its worldwide leadership position in phosphates-related products, the company said.

Lower production levels and exports of phosphate rock were balanced by higher global market prices for rock, while for fertilizers production levels were at a record high but prices were lower. In Asia, where India experienced increased production of local fertilizers, OCP was the main exporter of phosphoric acid.

CEO, Mostafa Terrab said: "Thanks to the group's competitive advantages and in spite of less favourable market conditions, OCP has registered above-average results in the first half of the year." He added that OCP relies heavily on its "industrial flexibility" and "commercial agility" to meet the requirements of a mixed global demand in the first half of 2019. As some sectors were more profitable than others in the global market, the company devised a working formula to ensure overall positive performance. "Our cost leadership has allowed us to maintain our margins in this context of overall price declines," Terrab said. "At the end of the first half of 2019, operating cash flow increased significantly compared to the same period of the previous year, thus enabling the group to reinforce its growth strategy and its cost leadership. Investment spending at the end of June 2019 is in line with our development program and we continue to realise savings thanks to the success of the completed projects."

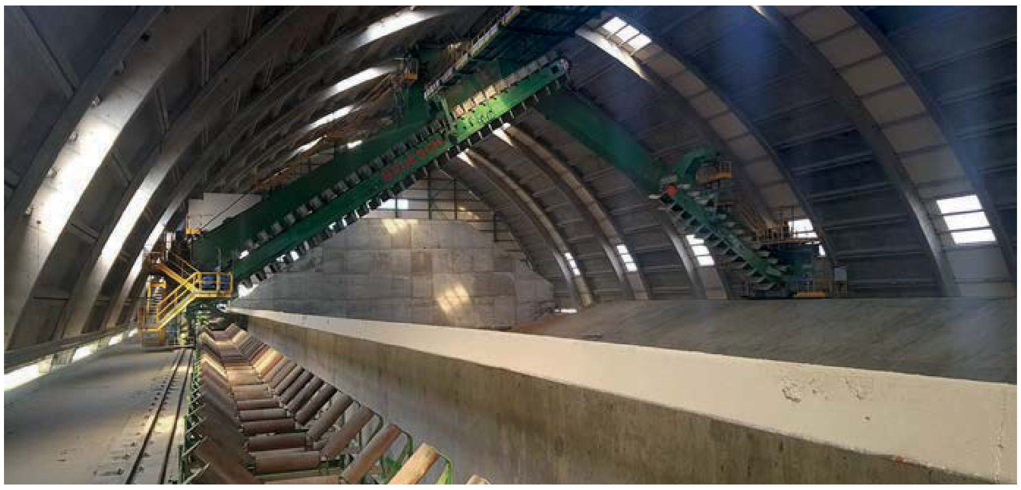
PHOTO: OCP

Bedeschi's conveying systems installed at OCP's Jorf Lasfar facilities.

OCP selects Bedeschi to provide conveyors

As part of its strategic development plan, OCP Group has chosen Bedeschi as the engineering, procurement and construction contractor for the expansion of the Jorf Lasfar plant and port to increase the volume of fertilizers that can be shipped by sea. The project consists of the installation of a 2000 t/h conveyor line stretching 5 km, for both fertilizers and phosphate rock. Bedeschi will provide the engineering, design, assembling and commissioning by integrating it with the already existing handling systems.

INDIA

Vedanta seeks approval to repair smelter

Vedanta is seeking approval from the state of Tamil Nadu to make repairs at its Sterlite Copper smelter at Tuticorin. The plant has been closed by government order for more than a year without the company being allowed access, and Vedanta says that the plant badly needs maintenance. Cooling towers and pipe ducts have reportedly collapsed, according to local media. The prolonged closure of the 400,000 t/a smelter has significantly cut India's copper cathode production, which has fallen by 40% from the previous year's figure to 457,000 t/a from its normal 660,000 t/a, according to official figures. India's copper exports have fallen by 87% to 50,000 t/a, and imports have more than doubled to 96,000 t/a.

After multiple court hearings, including a favourable verdict for Vedanta by the National Green Tribunal, the Supreme Court in February stalled the reopening, saying the environment court didn't have the jurisdiction to decide on the matter. It directed the company to file a petition with the state's high court.

RUSSIA

Sulphuric acid symposium held in Sochi

DuPont Clean Technologies held a sulphuric acid symposium in Sochi from October 15-16. The meeting focused on the key drivers of the sulphuric acid industry and the technology solutions that have been designed to address them. Attended by more than 60 members of the sulphuric acid industry in the CIS, the event presented, evaluated and discussed materials, processes, systems, services, equipment and technologies aimed at improving sulphuric acid plant operations, productivity and costs.

In nine sessions spread over two days, technology specialists from DuPont covered topics such as new developments in sulphuric acid catalysts, plant capacity increases and expansion, project execution and process design, troubleshooting and issue investigation, emissions control, lifecycle cost reduction and specific technology solutions. The symposium concluded with a roundtable discussion which focused on plant optimisation, turnaround improvements and environmental solutions.

Thierry Marin, managing director, DuPont Clean Technologies EMEA, explained, "The symposium is part of a range of events we hold around the world to discuss our latest technology innovations and to share best sulphuric acid operational practices. For our clients this workshop is a unique opportunity to share their experiences with *MECS*® subject matter experts and to discuss industry requirements in terms of productivity increase and emission reduction."

PhosAgro acid output up 18%

PhiosAgro has announced its third quarter 2019 results. Total fertilizer production for the 9 months to September was up 7.2% year on year to 2.5 million tonnes. Phosphate rock output was up 6.7% for the same period at 8.8 million tonnes. Growth in fertilizer production was driven by a 17% rise in DAP/MAP production following completion of technical overhauls at the company's production sites in Cherepovets and Balakovo at the end of last year. Growth was also supported by higher NPS production, which rose to 175,000 tonnes due to an increase in production of grades with lower phosphorus content, as well as an increase in the efficiency of production of sulphur-containing fertilizer grades following equipment modernisation.

In the third quarter, the company increased its production of sulphuric acid by 18.3% year-on-year to 1.59 million tonnes, which enabled PhosAgro to reduce purchase of this feedstock from third parties, following the modernisation of one of the production units at the Cherepovets site in December 2018. Increased self-sufficiency in sulphuric acid combined with a two-fold decrease in sulphur prices year-to-date made it possible for PhosAgro to lower the cost of fertilizer production, which will have a beneficial effect on profitability.

The company says that it expects preparation for the spring application season in key markets (including Russia and the CIS, Europe and Latin America) to start by the end of the year, which will support prices for its products. An additional positive growth driver is the favourable price ratio for agricultural products and fertilizers. At the same time, high volumes of accumulated inventory in the USA and southern Asia will continue to put pressure on the global phosphate-based fertilizers market.

SOUTH AFRICA

Phosphate project delayed again

London-registered Kropz, which is aiming to develop a phosphate mine at Elandsfontein in the Western Cape, says that it has taken a $49 million impairment due to further delays to the mining project. The mine has already taken a $20 million write down, after its originally scheduled start date of the second half of 2019 was pushed back to the final quarter of 2020. It is now conducting revised test work scheduled to last until the end of 2019, although the company says that the preliminary results, conducted by South African state-owned minerals research company Mintek and US-based Eriez had "confirmed the Elandsfontein ore body to be complex with regards to particle size distribution and grade variability".

"The provisional conclusion from the test work is that a reverse flotation modification to the current circuit will produce saleable product, but at lower grade than originally targeted by the company," Kropz said in a statement. "Therefore, and as a direct consequence of the prevailing depressed phosphate rock prices, an alternative process modification is being considered to deliver the required process efficiencies at viable economic returns," it said. "This will result in a consequential delay to the time required to bring Elandsfontein into production."

ITALY

Nuova Solmine completes testing of absorption tower

Italian speciality chemicals company Nuova Solmine, has completed testing on a new DuPont MECS ZeCor final absorption tower (FAT), designed and installed by DuPont Clean Technologies, at its double absorption sulphuric acid plant in Scarlino, Italy. The alloy tower performed below local emissions of limits 35mg/Nm³, and acid mist also measured considerably below the contractual performance guarantee of 30mg/Nm³.

With a capacity of approximately 1,700 t/d, Nuova Solmine's sulphuric acid plant in Scarlino operates 365 days a year, supplying sulphuric acid to Italy, as well as other countries in the Mediterranean basin, as well as Central and South America. By early 2017, the brick lining in the old FAT tower had started to deteriorate and require frequent maintenance, which affected production efficiency. DuPont was awarded the turnkey contract to design, execute, supply and erect a replacement tower made of lightweight and corrosion-resistant alloy in July 2017. From start to finish the complete project took 11 months, with the replacement of the old brick-lined tower taking place during a planned plant turnaround in August 2018. After passing testing, the new drying tower is performing well, with a lower pressure drop than specified and SO_3 acid mist emissions that satisfy environmental requirements.

"We wanted to replace our old final absorption tower with a highly efficient new tower that would guarantee constant reliable emissions control and not require as much maintenance as the last one did," said Gabriele Pazzagli, Scarlino site manager, Nuova Solmine. DuPont Clean Technologies could not only offer a performance and mechanical guarantee but also could help us to limit lost production time through a definite delivery and installation schedule."

Kirk Schall, global business manager, acid and scrubbing technologies, DuPont Clean Technologies said; "our aim is to enable our customers to reduce emissions while continuing operations without loss of production time. Our design and engineering teams therefore focus on achieving quality construction, timely delivery and simple installation of reliable and efficient equipment on minimal plot size, as this FAT installation demonstrates. That allows customers like Nuova Solmine to concentrate on their core business with minimal disruption."

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People

Nassef Sawiris, chief executive officer of OCI, has also been named as CEO of OCI's new joint venture with the Abu Dhabi National Oil Co. (Adnoc) – Fertiglobe. The announcement came with the notification of the completion of the transaction to combine Adnoc's fertilizer business with OCI's Middle East and North Africa (MENA) nitrogen fertilizer platform. Fertiglobe, based in Abu Dhabi, will combine businesses with 2018 sales of more than $1.7 billion. OCI holds a 58% stake in Fertiglobe and Adnoc the remaining 42%. The deal combined OCI's Egypt Basic Industries Corp., Egyptian Fertilizer Co., and Sorfert, with Adnoc's Fertil units. OCI says that Fertiglobe will be the largest export-focused nitrogen fertilizer platform globally, and the largest producer in the Middle East/North African region with a production capacity of 5 million t/a of urea and 1.5 million t/a of merchant ammonia. Fertiglobe, will now focus on the integration of the two businesses, which is expected to create significant value through the unlocking of commercial and technical synergies, the companies say.

To coincide with Global Fertilizer Day on October 13th, the International Fertilizer Industry Association (IFA) has announced that its 2019 Norman Borlaug Award has been given to **Dr Andrew Sharpley**. whose work has had a huge impact on helping farmers to better understand how to effectively manage phosphorus fertilizers to avoid losses.

Based at the University of Arkansas, Dr. Sharpley pioneered the development of new environmental risk assessment tools, based on his research findings, which have been used by farmers and agronomists, as well as regulatory and resource conservation agencies throughout the world, to develop cost-effective conservation strategies to protect water quality. By developing the P Index, a tool to identify which areas on a farm are most susceptible to phosphorus nutrient loss, Dr Sharpley has enabled farmers to more effectively target their fertilizer use, and helped reduce the amount of phosphorus lost to the environment in the US by an estimated 25,000 tonnes. The success of the P Index is highlighted by the fact that the US Department of Agriculture's National Resources Conservation Service (NRCS) has adopted it as the cornerstone of their nutrient management planning at Concentrated Animal Feeding Operations (CAFOs) in 49 states. The US Environmental Protection Agency and the NRCS also use the indexing approach to prioritize and target conservation measures across the country.

Dr Sharpley has received a wide array of recognition for his research and outreach efforts, including Fellow of the American Society of Agronomy and Soil Science Society of America and those Society's Environmental Quality Research and Soil Science Applied Research Awards. He was inducted into the USDA-ARS Hall of Fame in 2008 and in 2010 received the International Plant Nutrition Institute Science Award.

"I am honoured and humbled to receive this award. We need to better manage phosphorus for future generations. Transferring scientific research on the subject to the field enables more sustainable farming that benefits the farmers, society and the environment," said Dr Sharpley.

"We are delighted to distinguish someone who has worked so tirelessly to ensure that farmers have the right tools and techniques to manage phosphorus properly to grow more crops while minimizing their environmental footprint," observed Charlotte Hebebrand, IFA's Director-General.

Andrey Guryev, CEO of PhosAgro has been elected as a member of the management board of the Russian Union of Industrialists and Entrepreneurs (RUIE). Guryev has also been president of the Russian Association of Fertilizer Producers since October 2015. He is the First Deputy Chairman of the RUIE Committee on Corporate Social Responsibility and Sustainable Development, the Deputy Chairman of the Agricultural Industry Commission, and the Chairman of the Subcommittee for Agriculture, Processing and Forestry.

RUIE President Alexander Shokhin said: "The experience of the CEO of PhosAgro, a systemically important player in the global mineral fertilizer and agricultural industry sectors, who is involved in supporting national and global food security, will be extremely important for the RUIE's Management Board Bureau, especially in advocating for removing trade barriers in foreign markets."

Calendar 2019/20

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

13-14

European Sulphuric Acid Association General Assembly, ROME, Italy
Contact: Francesca Ortolan, Cefic
Tel. +32 2 436 95 09
Email: for@cefic.be

JANUARY 2020

29

ASRL Chalk Talks, CALGARY, Canada
Contact: Alberta Sulphur Research Ltd
Tel: +1 403 220 5346
Email: asrinfo@ucalgary.ca

FEBRUARY

3-4

SulGas Conference, MUMBAI, India
Contact: Conference Communications Office
Tel: +91 73308 75310
Email: admin@sulgasconference.com

24-27

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

MARCH

8-10

Phosphates 2020 Conference, PARIS, France
Contact: CRU Events
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

22-24

AFPM Annual Meeting, AUSTIN, Texas, USA
Contact: American Fuel and Petrochemical Manufacturers (AFPM),
1667 K Street, NW, Suite 700,
Washington, DC 20006, USA
Tel: +1 202 457 0480
Email: meetings@afpm.org
Web: www.afpm.org

APRIL

5-8

2020 Australasia Sulfuric Acid Workshop, BRISBANE, Australia
Contact: Kathy Hayward, Sulfuric Acid Today
Email: kathy@h2so4today.com
Web: www.acidworkshop.com

Countdown to MARPOL

PHOTO: EXXONMOBIL

The new IMO MARPOL (Maritime Pollution) 0.5% limit on sulphur content of marine fuel is due to come into force on January 1st 2020. This article looks at the likely consequences for refiners, ship owners and the sulphur industry.

While regulations on sulphur content of fuel have been tightening progressively around the world for the past three decades, by far the biggest single reduction that the industry has seen is due to come into force on January 1st next year, when the maximum permissible sulphur content of marine bunker fuels will fall from 3.5% to 0.5% by weight. This target has been set by the International Maritime Organisation (IMO) in order to reduce sulphur dioxide emissions from ships and associated health risks for people living in coastal areas. The change is particularly problematic for refiners, as the high sulphur fuel oil (HSFO) that ships have burned up to now has become a sink for much of the sulphur in the refinery system, and a widespread switch to low sulphur fuels will necessitate removing and dealing with much more sulphur than refiners have previously had to. How much sulphur and where it will be generated will of course depend upon how the shipping industry responds to the new regulation, and although as the deadline approaches the outlines of how things will work from 2020 on are becoming clearer, this is something which has attracted a great deal of uncertainty.

Options

The aim of the legislation is to reduce sulphur dioxide emissions, especially close to coastlines, where much of the world's population live. Sulphur dioxide has long been known to be a threat to human health, but medical studies have begun to find that long term exposure even to relatively low levels has significant effects on human health, especially among those most susceptible (children, asthmatics etc). The IMO calculates that a reduction from 3.5% to 0.5% sulphur in maritime fuels outside of established emissions control areas (ECAs) would reduce SO_2 emissions by 8.5-9.0 million t/a, leading to an approximate 77% reduction in global SO_2 emissions from international shipping, preventing more than 100,000 premature deaths per year. Because the aim is to lower SO_2 emissions, burning low sulphur fuel is only one option available for ship operators – the other is to install exhaust scrubbing technology which removes the SOx, NOx and particulates from it before the exhaust is released to air.

But the uncertainty has come from the projected level of uptake of scrubbing technology by the maritime industry, and that in turn has come from ship owners trying to quantify how expensive low sulphur fuels will be compared to high sulphur fuels, and whether there will be enough low sulphur fuel available, so that they can calculate whether the cost of installing exhaust scrubbers is worth it. The cost of installing scrubbers varies a little by ship size and type, but in general falls between \$3.0 million and \$4.5 million. Table 1 shows the costs by ship type, and Table 2 shows the economics of installing scrubbers for a very large crude carrier (VLCC). As Table 2 indicates, for large vessels in continuous service, the economics of installing scrubbers – assuming a \$300/t cost saving on fuel – is relatively straightforward, and most large vessels, which consume a greater proportion of bunker fuels than smaller ones, have moved to scrubbing systems. Norwegian classification society DNV estimates that by the end of 2019, around 2,700 ships will have installed scrubbers, representing only 4.5% of all merchant shipping in terms of numbers, but because of their size and greater number of in-service days, more like 15% of all bunker fuel consumption. This will rise to 3,600 vessels over the next few years. In the meantime, however, this still leaves 85% of all bunker consumption having to switch to low sulphur alternatives.

Non-compliance

As well as scrubbers and low sulphur fuels, there is technically a third option, which is not to comply with the regula-

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

tion at all, and deal with fines when and if they are awarded. Initially it was assumed that non-compliance rates would be high, perhaps up to 30% of consumption. However, the IMO has been seeking to tighten enforcement of the regulation, by switching the burden of enforcement away from 'flag states' – the country where the ship is registered, often 'convenience' flag states like Panama (where 25% of all shipping is registered) – to 'port states', where the ship will be operating from, and where local authorities can test the fuels available at dockside. Maritime insurers have also suggested that regulatory non-compliance could void a ship's insurance, bringing many shippers back into line. A study by Maersk on non-compliance with sulphur fuel limits in the European Emission Control Area (ECA) in 2015 found that only 3-9% of ships did not comply, and it may be that the figure for non-compliance worldwide will not be much higher than that. Maritime consultants ClipperData say that their projections are for 10% non-compliance in 2020, falling rapidly to 1-2% by 2023.

There is the potential for national non-compliance. In July, Indonesia's Ministry of Transportation announced it was exempting its domestic shipping fleet from the IMO regulations due to lack of availability of very low sulphur fuel oil (VLSFO) at Indonesian ports. However, in August state oil company PT Pertamina said that it will produce 380 million litres per year of low sulphur marine fuels from next year, and could meet the upcoming IMO standards, leading the Indonesian government to reverse its decision, and tell domestic shippers that they must comply with the regulations after all. Once again, it is assumed national non-compliance rates will be low.

Alternative fuels

Assuming 15% scrubber uptake and 10% non-compliance, that leaves 75% of bunker fuel demand to be met by low sulphur fuels. There has been some experimentation with alternatives to refinery fuels. The most widely touted alternative is liquefied natural gas (LNG). Other alternatives include methanol, and even ammonia, both of which, like LNG are widely available and widely carried by some ships, and all of which are considerably cheaper than conventional fuels. However, switching to LNG or other alternative fuels requires extensive modification and capital expense, and is probably only practicable for new builds. There are about a dozen methanol-powered vessels and around 400-600 LNG-powered ships in service or on order, the latter representing only 1% of bunker fuel consumption, perhaps rising to 2% over the coming five years. There also concerns longer term about carbon dioxide emissions and potential carbon taxes on CO_2 use which may limit adoption of LNG. Maersk has already said that it is seriously looking at renewable-based ammonia as a fuel in the long term (out to 2050) because of its zero carbon emissions.

Refiners

It seems that for the time being everything, then, depends on refiners being able to supply sufficient low sulphur fuel. Bunker fuel consumption is around 200 million t/a (3.7 million bbl/d), and our assessment above suggests that up to 150 million t/a of this will have to switch to low sulphur fuels. The two main options are very low sulphur fuel oil (VLSFO) and marine gasoil (MGO). Initially it was assumed that most consumption would be as MGO, which already meets the <0.5% sulphur standard. However, this would mean the world's shipping industry would now be competing for the same low-sulphur distillates used to make gasoline, diesel, jet fuel and heating oil, and potentially pushing MGO prices through the roof.

The alternative is to switch to VLSFO. However, the shipping industry was initially very sceptical about the quality of VLSFO and potential compatibility issues. It appears that extensive testing has eased many of these concerns, and VLSFO has proved to be cheaper and more widely available than expected, leading to a surge of interest in it as an alternative and some stockpiling ahead of the January 1st deadline.

Producing VLSFO requires substituting the high sulphur residue which is the main blend component of HSFO. There are essentially two ways that refiners can do this – substituting with very low sulphur residue, or substituting with vacuum gasoil, producing a so-called low asphaltene blend. Low sulphur residue production involves processing low sulphur crudes with less than 0.3% sulphur. This is the easiest option for refiners, and there are already signs that low sulphur crude consumption is rising, but there is not enough low sulphur crude available for all refiners to do this, and lack of supply will also drive up the price of low sulphur crude and drive down that for high sulphur crude (>0.7% sulphur).

Vacuum gasoil requires a vacuum (or atmospheric) residue desulphurisation unit, which are expensive. The low asphaltene content can also lead to the compatibility issues discussed above when blended with high aromatic products. VGO is usually fed to a cracker to produce gaso-

Table 1: **Cost of scrubber retrofits**

Category	Size	No. ships ('000)	Sailing time	t/d fuel	Total cons. ('000 bbl/d)	Scrubber cost (capex)
Dry bulk	Cape	1.7	70%	40	464	$3.7 million
	Panamax	2.5	60%	19	322	$3.4 million
	Other	7.0	42%	9	422	$3.2 million
Tankers	Large	2.7	64%	52	993	$3.9 million
	Small	11.8	50%	16	1,247	$3.2 million
Container	Large	1.0	57%	60	411	$4.4 million
	Small	4.3	45%	15	412	$3.6 million
Ferry	All types	9.6	16%	5	289	$3.2 million
Other		15.1	16%	3	264	$3.0 million

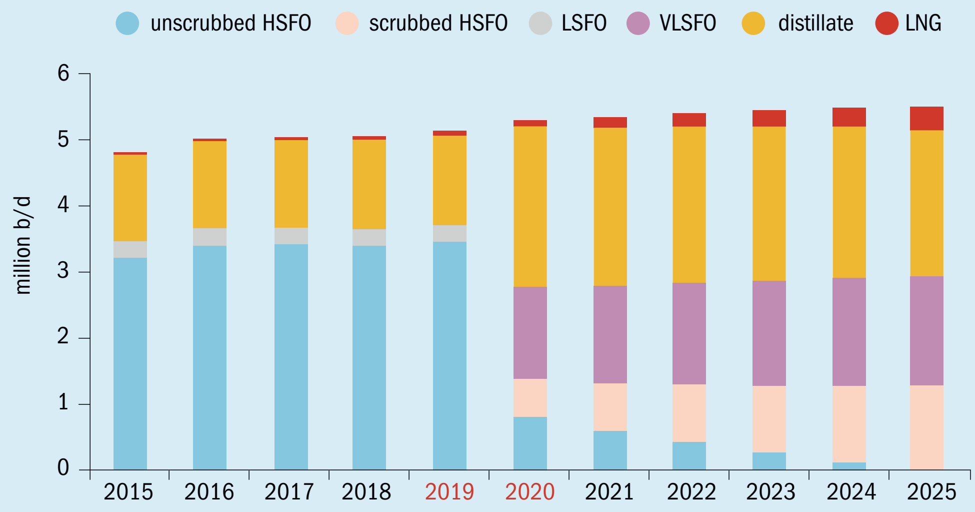
Source: 2020 Marine Energy

Table 2: **Scrubber economics (large crude carrier)**

HSFO price assumed	$300/t
VLSFO price assumed	$600/t
Vessel consumption (250 days)	70 t/d
Annual fuel cost saving	$5,250,000
Efficiency loss/year	$78,750
Maintenance cost/year	$100,000
Total savings	**$5,071,250**
Cost of scrubber installation	**$4,000,000**

Source: 2020 Marine Energy

Fig. 1: **Volume of marine bunkers by fuel type* 2015-2025**



Source: Wood Mackenzie

line, so switching to VLSFO production will also have a cost penalty in terms of lost gasoline output. Argus has suggested that this means production may be limited to seasons/places where there is an excess supply of gasoline, although there is currently a degree of oversupply in the gasoline market which may ease matters in the short term. There is a considerable volume of atmospheric residue desulphurisation capacity in Asia, especially China, and some parts of the Middle East. Meanwhile Northwest Europe and the US have more complex refineries which have the potential to supply both forms of VLSFO, depending on price incentives.

At the moment, the predictions are that of the 2.7 million bbl/d of low sulphur fuels required in 2020, around 1 million bbl/d will be supplied as VLSFO and 1.7 million bbl/d as marine gasoil, although some consultants place the amount of VLSFO higher. North America, the FSU and Middle East all have a net excess of middle distillate supply, which will also assist with MGO production. There are also increases in middle distillate capacity expected as part of 2 million bbl/d of refinery capacity increases in Asia in the period 2019-21. Figure 1 shows a typical prediction for the changes in bunker fuel consumption over the next few years.

The market for HSFO

All of this also means that there will be 2.7 million bbl/d of unwanted HSFO, and prices are forecast to fall considerably. There may be some uptake by power producers, but there will also be considerable incentive for the HSFO to be processed by coking. With HSFO expected to make a significant dent in margins for refiners that are unable to desulphurise residue, there will be a strong incentive to pay a premium for very low sulphur crudes. Complex refiners on the other hand, which are capable of upgrading and desulphurising high-sulphur residue, will benefit from the expected fall in the price of high-sulphur crudes. In a presentation at The Sulphur Institute's World Sulphur Symposium earlier this year, Adrian Tolson of 2020 Marine Energy predicted a symbiotic relationship for US and European refiners, whereby US refiners would see more profit in buying high sulphur crude and using their more complex refineries to upgrade this, as well as buying HSFO from Europe to process in their cokers, leaving lower sulphur US crude to be sold on to Europe for processing to VLSFO.

Price differentials

Much of what happens next year will depend upon the price spread between high and low sulphur crudes and high and low sulphur fuels. At time of writing (late October 2019), the price of HSFO ranges from $300-390/tonne, depending on region, and that of VLSFO from $435-480/t, or an average premium of $110/tonne for VLSFO. MGO is priced at $490-590/t, a premium of $200/t over HSFO. Next year MGO prices are expected to average $500/t, VLSFO around $435/t, and HSFO an average of $260/t, for a premium of up to $240/t, although Argus has predicted that this could be as high as $400/t. The price differentials are expected to drive more demand for scrubbers as well as additional refinery desulphurisation capacity.

Additional sulphur

The question that the sulphur industry is most concerned with is of course how much additional sulphur will be recovered as a result of these changes. If all of the HSFO that is expected to be displaced from the market were to have all of its sulphur recovered from 3.5% down to 0.5%, that would potentially represent an extra 4.1 million t/a of sulphur, which is the figure that the IMO itself calculated in a report two years ago. However, this simple arithmetical number must be discounted by all manner of ways in which the refining and shipping industries will cope, from blending with low sulphur fractions, power industry sales of HSFO, switching to low sulphur crudes, increased use of scrubbers by shipowners, and possibly even closures of some refineries that are not able to offload all of the HSFO that they produce. However initial expectations that up to an additional 2 million t/a of sulphur might be available have been revised downwards by some project delays.

Sulphur storage: environmental considerations

PHOTO: BBC

The long-term storage of sulphur can lead to fugitive dust and sulphuric acid contamination of ground and water if not handled correctly. What are the risks and how can they be ameliorated?

Above: Sulphur blocks at Syncrude's Mildred Lake upgrader, northern Alberta.

While sulphur is a very safe material, its handling and storage, especially for long periods, can produce potential health and especially environmental hazards. How to manage and ameliorate these hazards is a problem that the sulphur industry has grappled with for decades, and will continue to do so for as long as sulphur is generated in areas too remote for it to be conveniently shipped to market.

Hydrogen sulphide

As produced in a Claus plant, sulphur often contains dissolved hydrogen sulphide (H_2S) and polysulphides (H_2Sx), to a level of around 300 ppmv. This can be liberated during forming and storage and exceed the North American exposure limit of 10 ppmv, especially in covered or enclosed spaces, or when, as during block pouring, layers of liquid sulphur are spread over a large surface area. For this reason sulphur is usually degassed before being sent to storage. There is an equilibrium within even degassed solid sulphur which will lead to slow continued formation and liberation of small quantities of H_2S, but this will not be of a level sufficient to affect human health. ASRL conducted research in 2004 on H_2S and SO_2 emissions from freshly poured sulphur blocks which showed that only minimal emissions could be detected, with levels down to only parts per billion at a distance of 50 metres from the block[1].

Dust

Solid sulphur is a highly friable material, and one of the well known major hazards from its production, storage and handling is the generation of fine sulphur dust. Every time that sulphur drops from a conveyor, or is moved from one contained to another, perhaps via low loader or other vehicle, pieces of sulphur abrade against each other and fine particles of dust result. Good practise is therefore to make any such handling as minimal and as gentle as possible to avoid the generation of dust. Dust can also be controlled by the addition of surfactants or water – there is a whole separate article to be written about moisture content of sulphur and its effect on dust formation, and it is something which has been covered by this magazine on numerous other occasions[2,3]. The hydrophobic nature of sulphur can be overcome by the use of special water-based chemical surfactants. The wetted particles agglomerate to each other and larger particles making them more difficult to be picked up by the wind.

The main hazard associated with the dust is the risk of fire and explosion. In

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covered storage, sulphur dust can accumulate on roof beams or other flat surfaces, and be dislodged by impacts to create a dust-air mix which is potentially explosive.

Improperly isolated electrical wiring and equipment or exposed metal striking against stone can also provide sparks or sources of ignition. This is one reason why sulphur storage is usually in the open, so that wind and rain carry dust away before it accumulates. As an inert substance solid sulphur is essentially harmless, although the dust can cause some minor eye and lung irritation, and there are some reports of dermatitis in cases of extended, prolonged contact[4].

Concerns about fugitive dust from sulphur storage and handling led to restrictions on import of crushed lump sulphur to Chinese ports on the Yangtze River in 2018 – crushed lump sulphur has to be bagged before those ports will handle it.

Indeed, one of the reasons that flaked and slate sulphur has become increasingly uncommon and formed, granulated or prilled sulphur has become the main form in which it is shipped is because of the associated dust.

Sulphur block weathering

While sulphur dust has mainly been an issue for short term sulphur storage as prills, granules or crushed bulk, it can be a concern for sulphur block storage as well. Sulphur is applied as a liquid but as it cools to a solid it undergoes a phase change from monoclinic to orthorhombic sulphur. These forms have different densities and so this can lead to internal stresses and cracking as the sulphur cools. This makes block pouring a skilled procedure which must be done carefully to avoid or minimise structural cracking in the block, with liquid sulphur added in approximately 10cm layers and allowed to freeze before adding another layer.

Once the block is poured, temperature cycling in day/night cycles and freeze-thaw processes in cold conditions can cause mechanical stresses in the sulphur and it will again start to crack and erode. This may be exacerbated by wind and, in dry desert conditions such as the Middle East or Central Asia, wind-blown dust erosion. Wind barriers may help to protect against some of the worst of this, but it is an inevitable process.

The potential issue of sulphur dust emissions from block storage became something of a cause celebre in Kazakhstan in the late 2000s. Tengizchevroil (TCO) was processing associated sour gas from the Tengiz oil field northeast of the Caspian Sea. For economic reasons, sulphur was poured to block during the early years of the project – prior to the completion of the Caspian oil export pipeline in 2001, the oil was exported by rail and there was no spare rail capacity to export sulphur[5]. The sulphur stockpile eventually extended to 9.2 million tonnes, becoming for a time the largest in the world.

Government agencies, however, became concerned about the prospect of fugitive sulphur dust being blown from the stockpile and the potential effects on human health. Sulphur carriage in open rail cars was banned unless coated, and the sulphur blocks were reclassified as ‘production waste’, meaning that TCO began to incur penalties for their storage[6]. There were some complaints from people in the region about health issues, and although they were living too far from the sulphur blocks (in some cases as far as 80km) for there to be any direct causal link, it provided convenient ammunition for the government in the ensuing legal cases. There appeared to be considerable confusion between sulphur, sulphur dioxide, hydrogen sulphide and mercaptans in the literature that this generated (for example a Friends of the Earth publication on Kashagan published in 2007)[7].

The end result was a serious fine for TCO and a pledge to melt down and sell off the sulphur stockpile, which occurred over the next few years. However, it did also lead to some genuine scientific investigation into sulphur block storage under the conditions found in Kazakhstan and the potential effects on health and the environment, by Kazakh research institutes in conjunction with ASRL. The end result was that the health effects of dust emissions from sulphur blocks were found to be harmless to humans, although there is the potential for acidification of ground nearby from dust carried to surrounding areas. Attempts to ameliorate weathering by coating with limestone or cement were not found to be effective, but the addition of a surfactant and polymer surface film did increase resistance to external weathering[6,8].

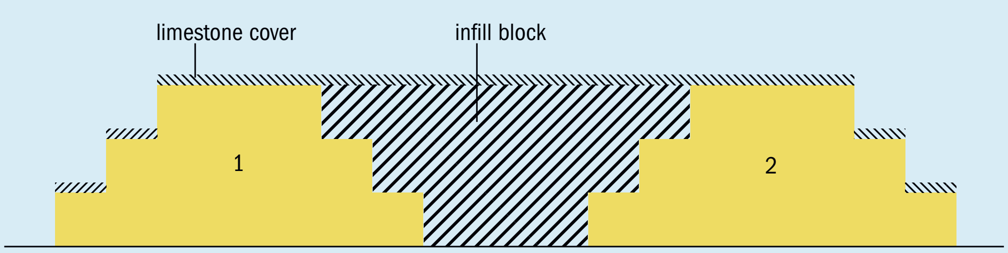
Fire

As noted, sulphur dust can present a fire and explosion hazard, but fire is also a major risk with solid sulphur storage. As well as the physical dangers of fire, in particular sulphur combustion liberates sulphur dioxide, which is toxic in high quantities and harmful to health even in relatively lower levels.

Fires can and do occur in large scale sulphur storage. Perhaps the most serious was when, during the 2003 US invasion of Iraq, retreating Iraqi forces set the sulphur storage facility at the Mishraq sulphur mine ablaze. The fire burned for over a month, releasing an estimated 600,000 tonnes of sulphur dioxide, and the resulting toxic plume dispersed over a large area, causing acute short term injuries in exposed military staff and local civilians, and has been linked to long term adverse medical effects in the local population. The act was repeated in October 2016, when Islamic State forces set fire to the sulphur stockpile at Mishraq for a second time, during the battle of Mosul, releasing another 160,000 tonnes of SO_2 over the course of several days[9].

Amelioration of fire risk requires continuous monitoring of sulphur storage and rapid response to any sulphur storage fire, as well as the provision of suitable

Fig. 1: Minimising surface area in long term sulphur storage



Source: ASRL Quarterly Bulletin No. 178

personal protective equipment for first responders and site staff.

Soil and water contamination

Perhaps the greatest environmental risk posed by long-term sulphur storage is contamination of local soil and water. This is caused by the action of sulphur-consuming bacteria – thiobacillae, which slowly oxidise sulphur to sulphuric acid. The rate of conversion is dependent upon the availability of oxygen and water and is accelerated by higher temperatures (although thiobacillae cannot survive temperatures higher than 45-50°C).

Bacterial (and water/oxygen) penetration into sulphur blocks is assisted by the cracks formed by weathering, which, in spite of sulphur's hydrophobic nature, can turn a sulphur block into a giant 'sponge'. The sulphuric acid is then carried away from the block by rain, and the resulting dilute acid, if not contained, will penetrate into the soil, where it can leach trace metals from naturally occurring soil minerals. This acidic and metallic mix contaminates soils and can get into ground water or local water courses.

Good practice when pouring sulphur blocks is therefore to only pour onto a polymer liner, clay or limestone base or better still an asphalt or concrete pad, and to surround the block with a run-off ditch of a similar impervious material to collect acidic run-off water. Typically this will be gathered in a collection pool, where the water can be treated with lime or sodium hydroxide before it is discharged. Unfortunately, best practice is not always followed. Reportedly, one of the reasons that the port of Nantong on the Yangtze River in China banned imports of sulphur and the storage of sulphur at the port in 2018 was because of contaminated waste water being pumped directly into the river, 1.8km upstream of the city of Nantong's main water intake.

Because this is one of the most pressing issues for long term sulphur storage, it has attracted a good deal of research from ASRL and others. One study found that the majority of sulphuric acid is produced in the uppermost 1 metre of a sulphur block.

Strategies suggested for minimising acid production included application of a biocide in this region to minimise the activity of sulphur oxidising microbes, but that attempts to minimise water or air ingress were unlikely to affect reaction rates. In most cases sufficient water is present within the formed sulphur to act as a host for the bacteria. Limiting block temperature to below 5C was also a potential strategy, but sulphur oxidation is exothermic and produces its own heat of reaction which may militate against this[10,11].

Eni has suggested that the activity of thiobacilli can be suppressed by the presence of "a high ionic strength environment", such as a solution of an inorganic salt like sodium chloride, with an ionic strength similar to sea water[12].

Below ground storage

In the late 1990s and early 2000s, ASRL investigated the possibility of below ground storage to see if the effects of weathering on sulphur blocks could be minimised. Two blocks were poured at Syncrude Canada's site in Alberta, one above the water table and the other below it. Monitoring of soil acidity was conducted, and the sulphur blocks were unearthed and examined after seven years. The results showed that the block stored below groundwater was badly contaminated and sulphuric acid had leached from it. The dry block however was in good condition, although this was in part because plant root structures and freezing winter conditions had helped prevent water penetration downwards[13].

Covered storage

Underground storage would require a significant investment in time and materials and an ongoing monitoring programme to make sure that there was no acidic leaching from the area. ASRL's next set of experiments therefore tried to extent the principles of the previo us study to look at covered storage of sulphur blocks using a variety of different materials[13]. Four blocks were poured at the Shell Burnt Timber gas plant in Alberta. One was a control, and the other three had a plastic cover, a limestone cover, and stucco concrete. The latter was chosen because, like the limestone, it produced an alkaline environment which would neutralise acid from the bacteria and inhibit bacterial growth. The plastic cover proved to be unsuitable, and was destroyed in a violent hailstorm – it was theorised that it might have been adequate if covered with a 30cm layer of gravel. The stucco concrete covering also deteriorated significantly over the three year lifetime of the study as a result of freeze-thaw weathering,

The limestone cover was the most effective – no change in sulphur quality was observed and no deterioration of the limestone occurred. Run-off from the block was neutral. The limestone also helped reduce temperature swings at the sulphur surface.

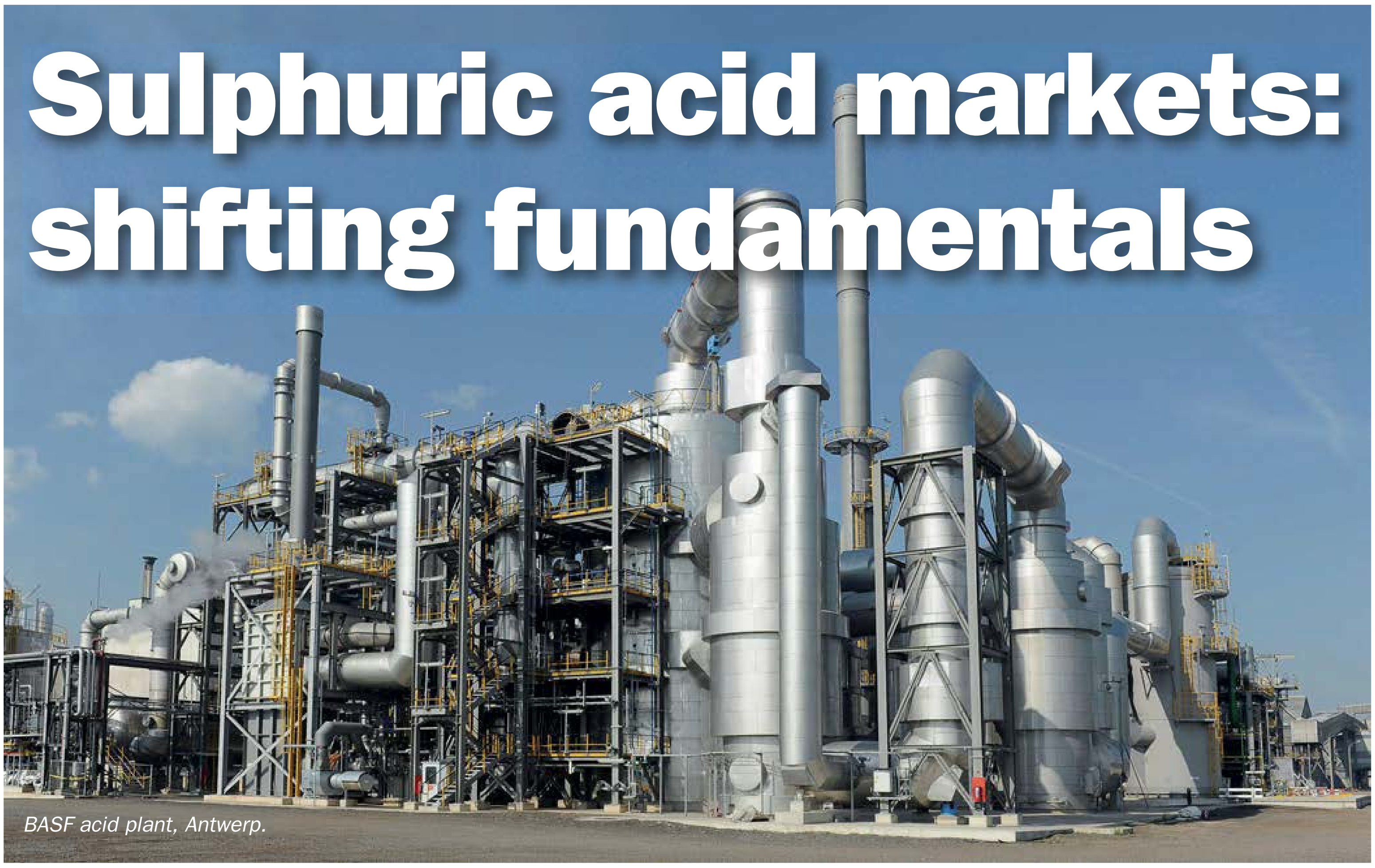
The project led to two suggestions for a commercial strategy. The first would be to simply take an existing sulphur block and, once it was deemed that the sulphur was not going to be sold in the short term, limestone chips could be placed on the horizontal surfaces of the block/ziggurat – acid formed on the vertical sides would be neutralised as it washed onto the lower horizontal shelf. A drainage trough with limestone and calcium oxide around the block would neutralise any remaining acid run-off.

Another option would be to reduce the exposed sulphur surface by filling in the area between two neighbouring sulphur blocks with sulphur, and then covering the horizontal surfaces with limestone, as shown in Figure 1. ■

References

1. P. Clark, Sulphur block storage of elemental sulphur: a simple strategy to prevent all emissions. *Sulphur 297*, Mar-Apr 2005, pp23-26.
2. J. D'Aquin, SUDIC 40 years on, *Sulphur 378*, Sept-Oct 2018, pp26-35.
3. Mind the gap, *Sulphur 356*, Jan-Feb 2015, pp24-29.
4. US National Library of Medicine Toxicology Data Network; Sulfur, Elemental, CASRN: 7704-34-9. Accessed October 2019.
5. Zh.S.Yelyubayev, *Some legal aspects of sulphur production, storage and transportation in Kazakhstan and CIS countries*, paper presented at Kazakhstan Sulphur Conference, Astana, July 2008.
6. Zh.S Yelyubayev, *Issues of statutory regulation of sulphur production, storage and transportation*, Almaty, 2009.
7. *Kashagan oil field development*, Friends of the Earth Europe, December 2007.
8. N. Chugunova et al, Characterisation of solid sulphur at Tengizchevroil. *J. Chem. Technology and Metallurgy 53*, Jan 2018, pp37-42.
9. Bjornam et al, The 2016 Al-Mishraq sulphur plant fire: source and health risk area estimation. *Atmospheric Environment 169*, November 2017, pp287-296.
10. T. Birkham, Controls and rates of acid production in commercial-scale sulphur blocks, *Journal of Environment Quality*, 2010.
11. P. Clark, Let the blocking begin – the chemistry of sulphur storage. *Sulphur 345*, Mar-Apr 2013, pp37-40.
12. F. Crescenzi et al, Control of acidity development on solid sulphur due to bacterial action. *Environ. Sci. Technol, 40*, 2006.
13. P. Clark, Storage of elemental sulphur: will it be necessary? How best to do it? *ASRL Quarterly Bulletin 178*, July-Sep 2016, pp11-21.

Sulphuric acid markets: shifting fundamentals



BASF acid plant, Antwerp.

PHOTO: HUGO PETERSEN

Declining imports of acid from China and increasing demand from Morocco, and eventually the Philippines and Peru are coming at the same time as the prospects of China becoming a net exporter.

The sulphuric acid market has been through a turbulent year in 2019. The end of 2018 saw prices at high levels, with acid markets ending the year very tight, and many volumes from major suppliers like South Korea and Japan already committed into 2019. Chilean smelters went through a series of shutdowns at the end of 2018 and into early 2019 to bring them into compliance with new SO_2 emissions regulations in the country, and the forced shutdown of the Tuticorin smelter in India also took another 1.2 million t/a of acid off the market, forcing consumers in India to look overseas for acid supply. The Pasar smelter in the Philippines was also closed, affecting another 1 million t/a of acid production. However, 2019 has taken a different turn, with acid prices falling through the year.

The seaborne sulphuric acid market is dominated by involuntary production from smelter acid producers. Sulphur burning acid plants tend to be located near sources of demand and their production is effectively captive. Only around 10% of acid trade is represented by sulphur burning acid production, with smelters making up the rest – the fortunes of the metal smelting market are thus key to sulphuric acid prices.

Sulphur prices

However, as sulphur burning acid production is an alternative/rival to acid from smelters, sulphur prices can also be a key determinant for acid prices. Sulphur prices have been falling this year, with oversupply in the market as refiners ramp up desulphurisation capacity and new sour gas projects continue to come on-stream. Low sulphur prices are often a signal for those who have the capability to burn sulphur instead of importing acid to start up their sulphur burning acid plants, which can also often generate electricity credits.

Acid demand

On the demand side, the major use is phosphoric acid production. Global phosphate markets are oversupplied, and prices are falling, in some cases to their lowest levels in 10 years. In October 2019 Chinese DAP offers were around $310/t f.o.b. and US New Orleans prices down to $265/short ton. As a result, major suppliers have started to initiate supply cuts. In July a group of Chinese DAP suppliers, representing about 70% of China's DAP capacity, agreed to production cuts of 800,000 t/a in the third quarter of 2019. In September, Mosaic announced the idling of 500,000 t/a of capacity at its Faustina and Uncle Sam phosphate facilities in St James, Louisiana. Chinese phosphate capacity has been falling slowly for several years as a result of new environmental restrictions on production. CRU estimates that the amount of phosphoric acid capacity at risk could total 4.3 million t/a in the period 2018-23. US import tariffs as part of the US-China trade dispute have not helped the prospects for Chinese exporters. In Morocco, OCP has been staggering its downstream phosphate production increases so as not to overbalance the market.

Copper markets have also been falling, and demand has been affected by the US-China trade dispute, although the fundamentals of the copper market remain positive, with copper becoming more difficult to mine and demand continuing to increase in developing economies. Cobalt, which is often mined with copper and which drives much investment in the southern African copper belt, is also at historically low prices, and Glencore has indicated that it will halt production at Mutanda in the Democratic Republic of Congo from the end of 2019, reducing need for 650,000 t/a of acid imports from Zambia.

There is better news from nickel. Demand for nickel for batteries continues to increase, requiring higher grade nickel production, and leading to a large-scale revival of interest in high pressure acid leach (HPAL) production, consuming large volumes of sulphuric acid. Tsingshan and its partners have two battery nickel projects in Indonesia with combined capacity of 110,000 t/a in nickel content and are aiming to start production from end 2020. PT Vale Indonesia and Sumitomo Metal Mining Co Ltd are also conducting a feasibility study of a 40,000 t/a battery nickel project based on HPAL, while Indonesia's Harita Group and China's Ningbo Lygend is planning another battery nickel plant. Indonesia's ore export ban has also led to a surge in nickel prices, supporting higher cost production.

Supply – East Asia

Japan and South Korea continue to be major exporters of sulphuric acid from their smelting industries. Korea exported 1.7 million tonnes of acid to July, around the same volume as 2018, which was a record year for Korean acid exports. However, the major factor in sulphuric acid markets will be developments in China. Chinese acid supply is expanding as China builds new copper and zinc smelting capacity. Argus puts the additions over the next few years (out to 2022) as 4.65 million t/a of acid capacity in northern China from copper smelting, 1.3 million t/a in central China from copper and zinc, and 1.1 million t/a in the northeast and northwest, from copper and zinc smelting. In total, a net 9.1 million t/a of additional sulphuric acid capacity is expected in China in the next three years.

During 2019, Chinese acid imports have already fallen from 2018, and are now likely to be surpassed by Chinese acid exports, which may reach 1.2 million t/a. China became a net acid exporter for the first time in 2018, to the tune of about 330,000 t/a, and this is set to increase in 2019. However, the problem for many smelters is that they are not close to ports and so their ability to export is limited. The major exporter currently is Two Lions, who exported 1.0 million tonnes in 2018. Earlier this year Two Lions signed a supply agreement with OCP in Morocco to ship them around 400,000 tonnes of acid during 2019. However, what is more likely to happen is that smelters may supply acid domestically, reducing import requirements and also displacing acid produced from pyrite roasting and sulphur burning. This in turn will reduce China's sulphur requirements and exacerbate the current surplus on the market.

Supply – Europe

The other major acid exporting region is Europe, which typically exports around 4 million t/a of acid. In the second half of 2019, a number of European smelters were offline, including Boliden, Aurubis, Nyrstar and Nuova Solmine, as well as KGHM in Poland. In Spain, Atlantic Copper suffered an unplanned outage which added to the tight acid supply availability from Europe.

Chile

Chile's acid output was reduced at the start of the year by the wave of smelter shutdowns to install SO_2 amelioration to meet new environmental regulations. Chilean smelter operating rates are a key component in determining the country's acid demand, which has been falling as smelter capacity expands and copper leaching production falls. Recently however things have been complicated by a wave of civil unrest. The demonstrations were originally triggered by a now-suspended rise in the price of metro fares in Santiago, but protesters have continued to march to express discontent over a wide variety of problems ranging from inequality to the high cost of healthcare. More than 20 people have been killed and 7,000 arrested during October 2019, and a state of emergency has been declared. Mine workers joined a general strike on October 23rd, and port workers have joined demonstrations at Iquique, Tocopilla, Antofagasta, Ventanas, and San Antonio, affecting acid imports.

India

The acid situation in India continues to be significantly impacted by the forced shutdown of the 1.2 million t/a Sterlite Copper smelter at Tuticorin, leading to increased Indian imports of acid to make up for the shortfall. The plant currently exists in legal limbo, with the High Court postponing a judgement, and owner Vedanta petitioning to be allowed back to conduct vital maintenance work. Even if the court case was resolved, it may be several months before the smelter could be operational again.

A review of AGIS VIII

The Acid Gas Injection Symposium (AGIS) is the only conference that focuses on the injection of CO_2, H_2S, and mixtures of the two either for disposal or for enhanced oil recovery. The eighth symposium was held in Calgary at the end of September 2019. Although AGIS covers three technologies: (1) acid gas injection (AGI), (2) carbon capture and storage (CCS), and (3) the use of CO_2 for enhanced oil recovery (EOR), in this review **Y. Wu** of Sphere Technology Connection and **J. J. Carroll** of Gas Liquids Engineering focus on the AGI aspects of the Symposium.

Acid gas injection (AGI) is basically a process where the acid gas by-product from the upgrading of raw natural gas is compressed to enough pressure where it can be transported via pipeline and injected into a subsurface formation typically for disposal. Typically, it is applied to cases where sulphur production is not an option, either due to low production rate (less than about 10 t/d) or where sulphur production is otherwise undesirable (say to avoid sulphur stockpiling).

The eighth AGIS (AGIS VIII) was held in downtown Calgary, Canada from September 24 to 27 in The Ramada Plaza. Attendees came from both Canada and the USA as well as from Europe and Asia.

The Symposium included 21 oral presentations and about 10 posters. In addition to the presentations, there were two excellent, half-day workshops. The symposium wrapped up with a lively round table discussion. Questions from the audience were addressed by the blue-ribbon panel of acid gas injection experts covering all topics related to AGI. Ultimately it was a great symposium and a lot of important information was promulgated.

Roundtable Panel (from left to right) Randy Franiel, Compass; Russell Bentley, WSP; Ray Mirreault, Independent Consultant; James van der Lee, VMG Schlumberger; Paul Maxwell, Corrosion Resistant Alloys (CRA); Alberto Gutiérrez, Geolex, John Carroll, Gas Liquids Engineering.

Acid gas water content – from the lab to the field

Although acid gas is a mixture of CO_2 and H_2S, both highly problematic components, engineers seem to spend more time worrying about the presence of water in the mixture. Liquid water, in combination with the acid gas, leads to problems with corrosion and thus materials selections. In addition, at lower temperatures the presence of water can lead to the formation of hydrates. The water content of acid gas mixtures was the subject of the keynote speaker, Rob Marriott from the **University of Calgary** and **Alberta Sulphur Research**, both in Calgary, Alberta.

Water content of H_2S – a review

In a similar vein, Eugene Grynia of **Gas Liquids Engineering** and Bogdan Ambrożek of the **West Pomeranian University of Technology** in Szczecin, Poland had a poster that thoroughly reviewed the water data for pure H_2S dating back over 100 years.

Possibly the first AGI in China

A poster presented by the Chinese company **SINOPEC** drew some interest. The poster outlined the preliminary design for what could be the first acid gas injection project in China. The project is at the Tahe oilfield, in Xinjiang province in western China and the AGI will replace a LoCat™ scheme currently used at that field. The acid gas is about 47% CO_2 and 42% H_2S and is saturated with water from an amine unit and flows at a maximum rate of about 0.7 million scf/d.

In a separate paper from **Xi'an Shiyou University** in Xi'an, China graduate student Zhu Zhu gave a series of detailed calculations for the injection pressure for the Tahe site. She presented many scenarios to obtain an estimate of the required injection pressure at the Tahe site.

AGI at Kaybob plant in Alberta

Rinat Yarmukhametov from **Gas Liquids Engineering**, Calgary, Alberta presented a review of the acid gas injection project at SemCAMS Kaybob plant in Alberta. The scope of work was to complete detailed engineering (process, civil, mechanical, electrical, instrumentation and controls) of the two acid gas injection compressors, including the suction piping from the existing acid gas knockout drum, the discharge piping to the wellhead, as well as utility piping to/from the compressors (instrument air, fuel gas, flare, drains, etc.). The flow rate for the acid gas was approximately 3.7 million scf/d and various mixture compositions were examined.

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Leak detection for acid gas pipelines

An overview of pipeline leak detection systems LDS) was presented by Shouxi Wang from **Xi'an Shiyou University**. Prof. Wang first presented some theoretical background followed by some work in his laboratory. Quick and reliable leak awareness and alarm for the acid gas pipelines are the key and common concerns due to the toxicity, hazardous effects and high pressure. There are many different leak detection methods and systems available for gas/liquid pipelines, such as the methods defined by API 1130, acoustic and fabric leak detection system, and distributed or fix point H_2S sensor along the pipeline. Prof. Wang discussed the features and behaviour of the acid gas flows with and without leakage, the selection consideration and expected performance of LDS over different acid gas pipeline scenarios, and the implementation and operation of the LDS.

Blow out recovery from an acid gas well

Ray Mireault, an Independent Consultant from Calgary, Alberta gave a presentation on blowout recovery for acid gas injection wells. How does the industry develop specialised recovery equipment and procedures a priori, to quickly stop a blowout from an acid gas injection (AGI) well while protecting health, safety and the environment? This paper presented an ongoing process to address the challenge and was a follow-up to the paper he presented at AGIS VII.

Acid gas disposal in BC

Michelle Gaucher and Mark Hayes from the **British Columbia Oil & Gas Commission** in Victoria, BC provided a brief look back, a summary of the current state and a future plan for acid gas injection in BC. Acid gas disposal has been a part of mid-stream business in BC for over 20 years, but in that time, the source of the gas supply has changed significantly. The next 20 years is likely to bring more challenges to this area of hydrocarbon processing. From public pressure on impacts of hydrocarbon production to challenges of pore space for storage, the commission is working to understand and address issues proactively.

Seismic data for acid gas wells

Alberto Gutiérrez and David White of **Geolex, Inc.** in Albuquerque, New Mexico presented a paper on the use of 3D seismic data to identify and locate appropriate high capacity reservoirs in carbonate rocks in the Permian Basin of southeastern New Mexico. The results of the geophysical study conducted indicated that this technique was useful in identifying areas within the Devonian-Fusselman section with enhanced secondary porosity due to paleo Karst features and enhanced dolomitisation. This was a follow-up and update to their paper at AGIS VII.

Reciprocating compressors in acid gas service

Dan Hannon of **Ariel Corporation** in Mount Vernon, Ohio discussed the application of reciprocating compressor for acid gas service. Acid gas injection service includes gas compositions mainly comprised of hydrogen sulphide and carbon dioxide. These influence the selection of reciprocating compressors in several ways. The heavier mole weight of these gasses may require operating at slower speeds. The higher pressures of injection service may also require operating at slower speeds. Both hydrogen sulphide and carbon dioxide have dew points near normal operating pressures and temperatures typically found in acid gas injection services. How the different proportions of H_2S and CO_2 affect the dewpoint of the gas, and how to avoid condensates between stages of compression was discussed.

Salt precipitation at a CO_2 injection well

Another interesting paper reported on the Aquistore project. Although technically Aquistore is a CCS project, the observations presented are directly related to AGI. At Aquistore, CO_2 is injected into an aquifer at a depth of about 3,400 m. A paper presented by Stephen Talman of the **University of Alberta**, Edmonton, Alberta, showed that the injection of CO_2 dried the brine sufficiently that solids precipitated. He presented pictures and movies from a downhole camera which showed the salt precipitation.

The viscosity of elemental sulphur

Ther Best Student Paper was presented by Mitchell Stashick from the **University of Calgary**. The topic of his award-winning presentation was the effect of hydrogen sulphide on the viscosity of elemental sulphur, which was a step in the design of the subsurface injection of sulphur.

CO_2 solubility

These included two papers from the **University of Pau**, in Pau, France. Marie Poulain presented new experimental data for the solubility of CO_2 in brines at high temperatures and high pressures and also on the induced corrosion of materials. Esther Neyrolles presented an experimental study of the liquid vapour equilibrium of the complex system water-CO_2-O_2-NO_x under pressure.

Speciation of CO_2 measurement in amine solutions

Karine Ballerat-Busserolles from **University of Clermont Auvergne** (UCA), Clermont-Ferrand, France, presented a paper on the speciation of amine solutions in the presence of carbon dioxide measured using infrared spectroscopy. This was a part of a research project at UCA looking for new amine-type solvents for acid gas removal.

Solubility of gases in mixtures of DMPEG

Kurt Schmidt from **Schlumberger** gave a presentation on the solubility of hydrogen sulphide and carbon dioxide in mixtures of dimethyl ethers of polyethylene glycol (DMPEG). DMPEG is a physical solvent used for acid gas removal commonly called Selexol™. This paper presented new experimental data and modelling based on the Peng-Robinson equation of state and Henry's Law using the Krichevskii-Illanskaya equation.

Workshops

Acid gas injection design

The first workshop was presented by John Carroll from **Gas Liquids Engineering**. This workshop focused on two aspects of AGI: (1) physical properties of and phase behaviour of acid gas mixtures and (2) design of the components of an acid gas system including the compressor, pipeline and injection well.

Injection well design

The second workshop was on injection well design, led by Russell Bentley from **WSP** in Houston, Texas with input from **Halliburton**, **Baker-Hughes (GE)**, and **Corrosion Resistant Alloys**. This workshop covered reservoir selection, well planning and design, pressure control (packers and shut-in valves), wellheads, material selection, and corrosion.

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BTX destruction in the Claus thermal oxidiser

Acid gas enrichment (AGE) is a commonly employed technique that can be used to increase the H_2S content of acid gases being fed to a sulphur recovery unit (SRU). In some cases, the AGE vent gas, enriched in CO_2, is routed directly to the thermal oxidiser. If the lean acid gas being enriched contains appreciable levels of benzene, toluene, and/or xylene (BTX), it is possible for BTX to slip through the amine of the AGE, along with the CO_2, and be fed to the thermal oxidiser. However, experimental data pertaining to conditions required for BTX destruction within the thermal oxidiser are lacking. In this context, ASRL has investigated the impact of various BTX concentrations in the thermal oxidiser. **D. Li**, **N. I. Dowling**, **C. B. Lavery** and **R. A. Marriott** of Alberta Sulphur Research Ltd discuss the experiments and the results.

The modern modified Claus process is designed to convert H_2S to elemental sulphur as well as to transform other contaminants in the stream into more environmentally benign N_2, CO_2 and H_2O[1]. While the above goals are primarily achieved in the thermal reactor and across the catalytic convertors, small amounts of various sulphur species and other contaminants are still present in the Claus tail gas. The last step of tail gas treatment, prior to release to the atmosphere, includes incineration of any persisting sulphur species and/or other contaminants in a thermal oxidiser where the temperature is in the range of *ca.* 500-800°C. As alluded to, the primary purpose of the Claus thermal oxidiser is to oxidise reduced sulphur species, such as H_2S, COS, CS_2 and S vapour to SO_2. Any H_2 or CO present in the tail gas may also be oxidised depending on the operating temperature of the unit. Thus, the thermal oxidiser unit can also be used to destroy CO, by oxidation to CO_2, in order to meet emission standards where mandated.

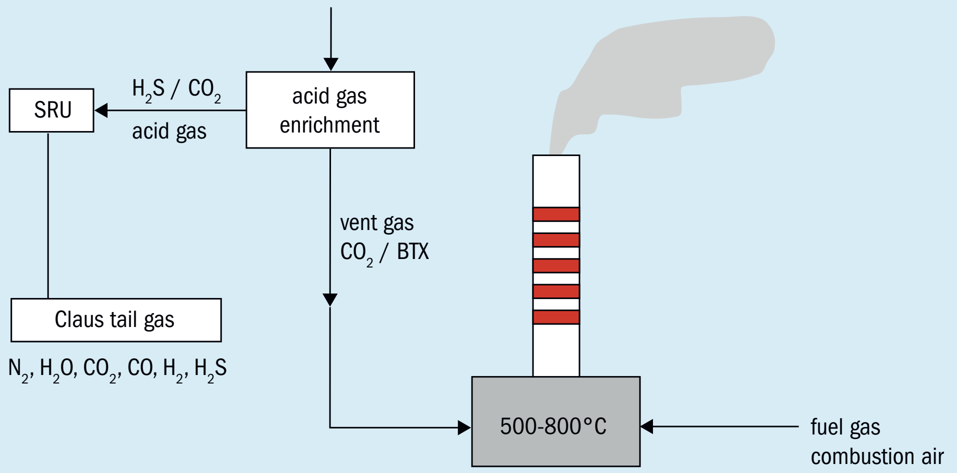
A laboratory study performed by ASRL in 2008 examined the chemistry and kinetics of Claus tail gas incineration[2]. This study provided the standard Arrhenius kinetic parameters, A and E_a, for the oxidation of H_2S, COS, CS_2, H_2 and CO based on the overall second order rate law,

$$-\frac{d[X]}{dt} = k[X][O_2]$$

which assumes first order dependence on the species being oxidised, $[X]$, and $[O_2]$. This study showed that the standard rate or ease of oxidation of the reduced sulphur compounds (H_2S, COS and CS_2) was greater than that of H_2 and CO, with complete oxidation requiring temperatures of 600-700°C and 800°C, respectively, for these species.

Ammonia (NH_3) can also be present in the stream feeding a thermal oxidiser. During the processing of natural gas and refining of high-sulphur crude oils, incomplete destruction in the thermal reactor can result in some NH_3 slip through to the thermal oxidiser. Furthermore, some refineries employ a two-stage stripping process of sour water which produces separate streams for H_2S and NH_3, with the NH_3 stream being sent directly to the thermal oxidiser. Recent investigations at ASRL on NH_3 destruction under Claus thermal oxidiser conditions has shown that the relative ease of oxidation is similar to that of H_2 and CO, requiring a temperature of 800°C for efficient destruction. The presence of NOx was further shown to increase NH_3 conversion at lower temperatures of 600°C via rapid thermal de-NOx chemistry involving reaction of NH_3 and NOx[3].

Fig. 1: **Schematic illustrating how BTX can reach the thermal oxidiser during AGE**



Source: ASRL

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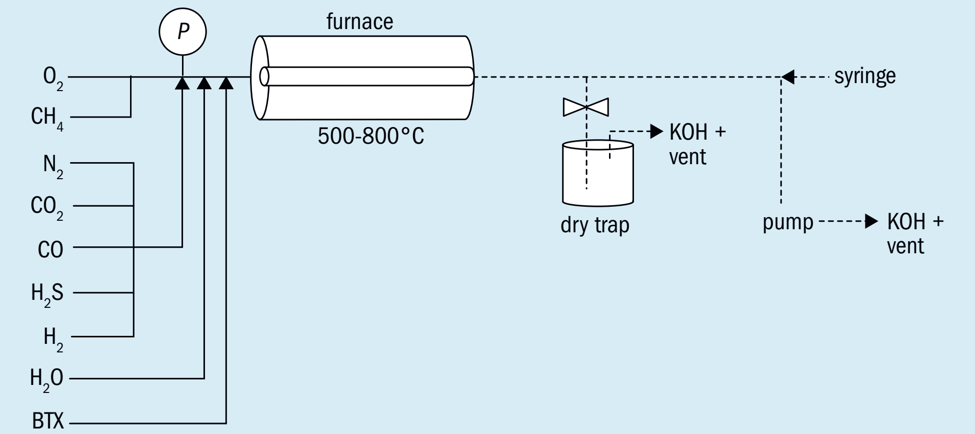
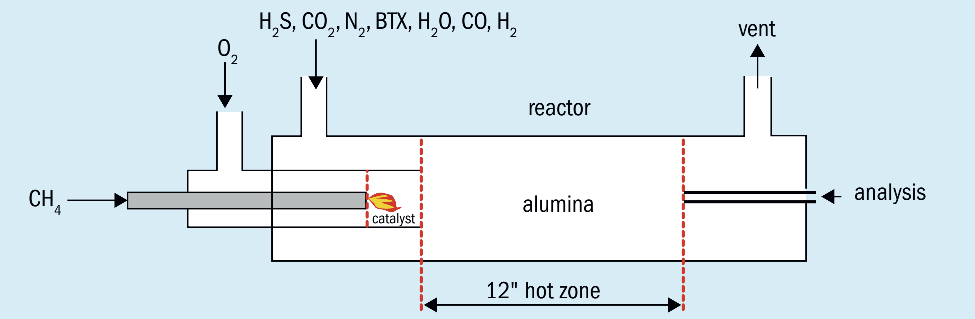
Until the current study, the direct impact of BTX on tail gas incineration had not been addressed. Acid gas enrichment is a reasonable method for increasing acid gas quality and thermal reactor temperature; however, with acid gas enrichment, some impurities in the acid gas, such as BTX, can make their way past the sulphur recovery unit and into the thermal oxidiser, as shown in Fig. 1. This article describes the results of ASRL laboratory studies investigating BTX destruction under the thermal oxidiser conditions. More specifically, we report on the temperature needed for complete BTX destruction along with the corresponding effects of concentration and residence time.

Fig. 2: **Simplified schematic of experimental apparatus**



Source: ASRL

Fig. 3: **Schematic of experimental apparatus**



Source: ASRL

Table 1: **Calculated experimental feed for the BTX destruction study**

Adiabatic temperature		**500°C**		**600°C**		**700°C**		**800°C**	
Comp	**Tail gas**	**Fuel gas**	**Air**	**Fuel gas**	**Air**	**Fuel gas**	**Air**	**Fuel gas**	**Air**
N_2	47.75		38.94		47.40		57.56		69.48
CH_4	(T0.05) 0.35	1.03		1.98		3.12		4.47	
CO	1.20								
CO_2	24.00								
H_2O	24.00								
O_2			10.35		12.60		15.30		18.47
H_2S	1.20								
H_2	1.50								
Moles	100.00	1.03	49.29	1.98	60.00	3.12	72.86	4.47	87.95

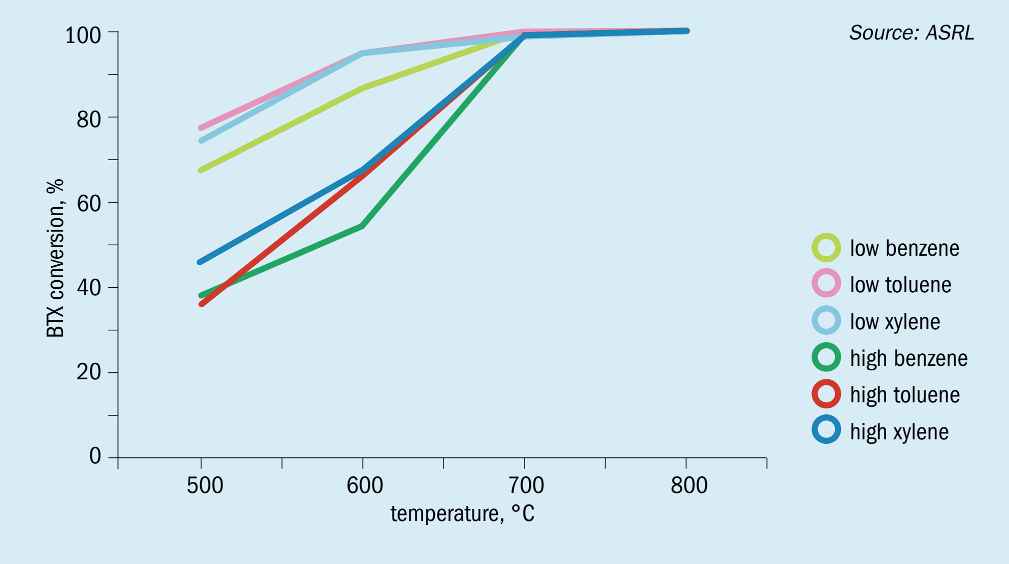
Source: ASRL

Experimental section

The laboratory experiments in this study were performed using an electrically heated single-zone furnace (Lindberg 1500°C Model) and a fully dense ¾" i.d. alumina tube (Vesuvius McDanel 998 alumina) that was 28" in length as the reactor. A concentric arrangement of three tubes for the inlet of the feed gases to the reactor was used for introducing the different streams into the furnace hot-zone. A schematic of the experimental setup configured for incineration of the base tail gas feed is shown in Figs 2 and 3, consisting of CH_4 in the centre tube, O_2 in the first annular space and the tail gas stream in the outer tube. This arrangement for the feed gases is meant to simulate staged combustion of the fuel gas in an actual thermal oxidiser. This design also limits any potential conversion within the ramp-up zone of the furnace by locating the end of the O_2 delivery tube at the beginning of the hot-zone section. Full combustion of the CH_4 prior to entering the hot zone of the furnace was ensured by retracting the end of the inner CH_4 tube into the O_2 delivery tube, along with placement of a CuO/Al_2O_3 catalyst in the recess. The full amount of O_2 sufficient for combustion of the CH_4 and oxidation of all the H_2S, CO and H_2 was introduced together. Thus, the incineration chemistry did not occur until the tail gas stream was allowed to mix with the CH_4 combustion stream at the beginning of the hot zone.

A set of experiments consisting of four temperatures of 500, 600, 700 and 800°C were performed with the full tail gas feed at residence times spanning 1.1-2 seconds. A tail gas composition containing N_2, H_2S, CO_2, H_2O and BTX along with CO and H_2 was used. The feed for each experiment was calculated by varying the amount of fuel CH_4 and air, so as to give the desired adiabatic temperature and 3% excess O_2 in the total 'stack' gas. This design is meant to mimic the input of fuel gas and air into an actual thermal oxidiser. These calculated feeds are shown in Table 1. In order to simplify the feed setup, 1) BTX was considered as CH_4 to simplify the calculations; 2) only a single tail gas flow was used with the amount of CH_4 and O_2 added to the feed being varied according to the calculations for a given adiabatic temperature. Actual residence times at the various temperatures tested were calculated as follows: t(500°C) = 2 s; t(600°C) = 1.65 s; t(700°C) = 1.37 s and t(800°C) = 1.13 s.

Fig. 4: **Conversion of BTX under the thermal oxidiser conditions**



Benzene, toluene, and xylene were first delivered individually to examine the behaviour of each species under full tail gas conditions, and then blended to test for any mixing effects. Two concentrations for BTX in the feed were selected: low: 300 ppmv and high: 3000 ppmv.

Analysis of the product stream was performed by sampling through a capillary tube (2 mm i.d.) to avoid longer quench times (*ca.* 200 ms) in the cool-down section of the furnace. The extracted gases were dried by passing through a P_2O_5 cartridge to remove both H_2O vapour and sulphur from the stream, providing the analysis on a dry and S-free basis. Analysis of the gas stream for N_2, CO_2, CO, H_2S, COS, SO_2, CS_2, CH_4 and BTX was performed on a Varian 3800 gas chromatograph equipped with Porabond Q and Molsieve 5Å columns and thermal conductivity (TCD) and flame ionisation (FID) detectors. Hydrogen and oxygen were analysed on a separate SRI 8610 gas chromatograph with a TCD detector using argon as carrier gas.

Percent conversions were calculated using the following equation:

$$\% \text{ Conv of } X = \frac{(X_i - X_f)}{X_i} \times 100$$

where the subscripts *i* and *f* refer to initial and final moles.

Results and discussion

Effect of temperature and concentration

BTX is comprised of aromatic compounds known for their stable structures consisting of a 6-member aromatic ring. However, any branches on the benzene ring, *i.e.* methyl groups, destabilise the resonance (lower the aromaticity) and thus increases the reactivity. Therefore, xylene should be more reactive than toluene and benzene should be the least reactive component of BTX because of its undisturbed resonance structure. Indeed, the activation of xylene and toluene should occur at the methyl groups first which will eventually lead to the breakdown of the remaining structure.

The BTX conversions measured across the experimental temperature range when added as individual components, in low (300 ppmv) and high (3000 ppmv) concentrations, are presented in Fig. 4. Residual BTX was observed in all cases in the 500-600°C range, and in most cases the conversions follow the order of X>T>B, which is in agreement with the previous discussion. However, >99% conversion was observed for all aromatics in the 700 and 800°C experiments.

At 500°C, BTX conversions were in the range of 67-77% when the feed levels were *ca.* 300 ppmv, however, conversions dropped to 13-38% when the feed level was increased to 3000 ppmv. Clearly, BTX conversion under thermal oxidising conditions is concentration dependent, and from a kinetic perspective, the reactions for BTX conversion are not 0^{th} order. At 600°C, conversions increased to 86-95% at low BTX levels and to 54-68% at high levels. At 700 and 800°C, no significant difference in conversions was observed at either low or high BTX feed levels as in all cases >99% conversion was observed.

Destruction of BTX mixture

Based on the results above, ASRL chose an experimental temperature of 800°C to test the destruction of BTX when added as a mixture; total BTX concentrations in the feed were either 300 or 3000 ppmv. While employing the same test feeds, an experimental temperature of 500°C also was tested to see if there was any secondary influence associated with mixing the BTX components.

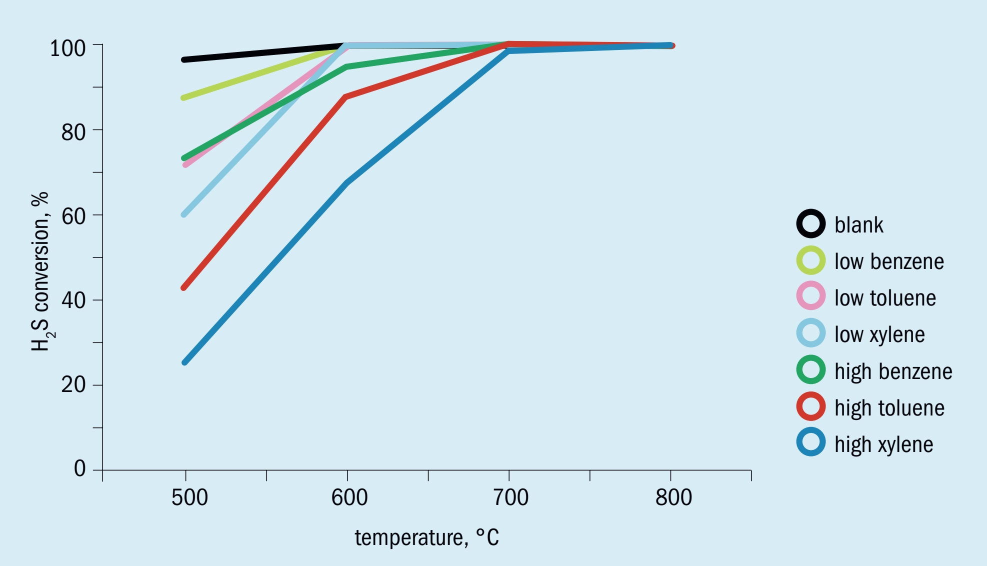
The results from experiments investigating BTX destruction when added as a mixture are presented in Table 2. In both the low and high concentration tests

Table 2: **Experimental BTX conversions when added as a mixture**

Temperature (°C)	Residence time (s)	BTX concentration (%)	Conversion (%)					
			benzene	toluene	xylene	H_2S	CO	H_2
500	2.0	0.010/0.010/0.010	55.45	80.91	80.91	91.57	-12.39	-9.67
500	2.0	0.100/0.100/0.100	33.95	45.06	61.41	68.06	-25.54	-10.51
800	1.13	0.010/0.010/0.010	100	100	100	100	99.48	100
800	1.13	0.100/0.100/0.100	100	100	100	100	96.52	100
800	0.5	0.010/0.010/0.010	100	100	100	100	79.54	99.36
800	0.5	0.100/0.100/0.100	86.57	96.84	100	100	-8.03	81.08

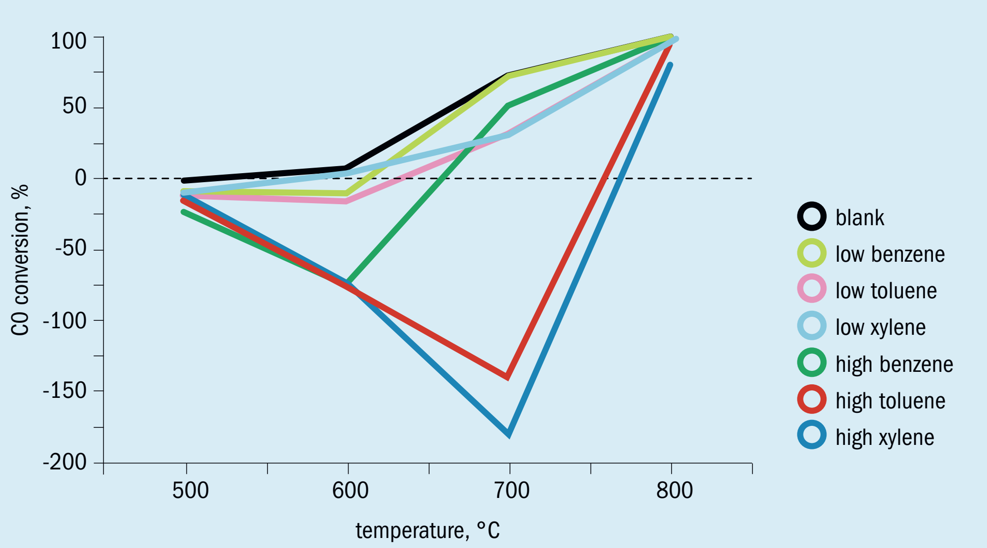
Source: ASRL

Fig. 5: **Conversion of H_2S in tests where BTX was added as individual components**



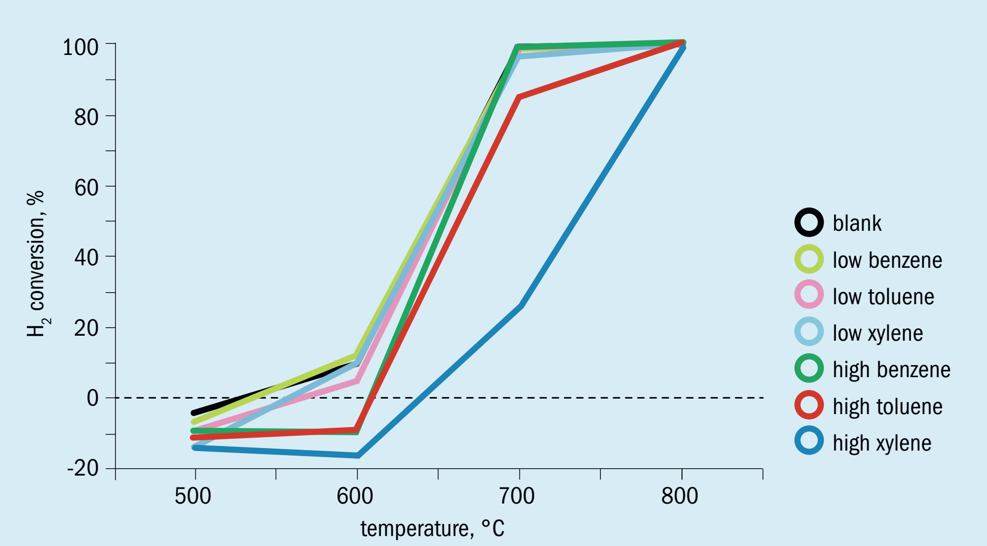
Source: ASRL

Fig. 6: **Conversion of CO in tests where BTX was added as individual components**



Source: ASRL

Fig. 7: **Conversion of H_2 in tests where BTX was added as individual components**



Source: ASRL

complete conversion of all aromatic species at 800°C was observed. At 500°C, residual BTX levels were in line with the conversions measured when the aromatics were added to the feed as individual components. Again, the relative ease of the aromatic conversions in these mixture tests was X>T>B.

Effect of residence time

Thermal oxidiser residence times are typically designed with 0.5 s in the combustion chamber and the stack volume adds another 1.0-1.5 s of residence time; stack temperature is still high enough (650-800°C) for combustion to occur. However, in Europe and in some parts of the Middle East, it is not uncommon for a heat exchanger to be present before the stack to recover the combustion chamber heat as high pressure steam. This cools the process gas from the combustion chamber down to *ca.* 350°C before entering the stack and thus no further combustion can take place. Based on this, ASRL again tested the low and high concentration BTX mixtures at 800°C but with a shorter residence time of 0.5 s. As can also be seen in Table 2, at 800°C, a residence of time 0.5 s was sufficient for quantitative BTX conversion in the low concentration test, but in the high concentration test some residual toluene and benzene was observed in the product stream.

The influence of BTX on the conversion of other feed components is perhaps more important than just monitoring the conversion of BTX itself. Indeed, in the high concentration BTX mixture test (T = 800°C; residence time = 0.5 s), H_2 and especially CO combustion suffered considerably from the shorter residence time of 0.5 s.

Influence of BTX on conversion of other feed components

During this study, the conversion of H_2S, CO, and H_2 were also monitored to establish their interactions with BTX in the thermal oxidiser, where conversions of H_2S, CO, and H_2 are presented in Figs 5, 6, and 7 respectively.

In previous studies[2,3], H_2S was readily oxidised at temperatures over 500°C and this performance was observed again in the blank tests of the current study (Fig. 5). However, the results show the presence of BTX has a negative impact on H_2S conversion at temperatures below 700°C. At 500°C, xylene impeded H_2S conversion significantly, while toluene and benzene had less of an influence. Additionally, higher concentrations of BTX led to lower H_2S conversions. At 600°C, the influence of BTX on H_2S conversion was less and at 700°C and above, near complete or complete H_2S conversion was observed in all cases. Rather than BTX hindering conversion of native H_2S in the feed, H_2S is likely produced as an intermediate or side reaction during BTX combustion. A more detailed discussion on possible reactions of BTX to form H_2S can be found in references 4 and 5.

As shown in Fig. 6, in the blank test, a temperature of 800°C was required for quantitative CO conversion. Similar to what was observed for H_2S, addition of BTX to the feed also had a negative impact on CO conversion. Most notably, in the high toluene and xylene concentration tests, negative conversions in the 140-180% range were observed. However, at 800°C, all CO conversions were >99% except for in the high xylene test. One can infer that a negative CO conversion in this study suggests that CO is produced as side reaction or intermediate during BTX destruction. A more detailed discussion on CO formation under the current conditions is presented in the following section.

H_2 conversion was more facile than CO under the current test conditions but generally followed the same trends observed for CO (Fig. 7). There was no real difference in H_2 conversion between the control test and the low BTX concentration tests. However, a considerable drop in H_2 conversion was observed in the high BTX concentration tests in the 600-700°C range but, again, complete conversion across all experiments was achieved at 800°C.

Possible route of BTX destruction

From their results ASRL can propose some elementary steps for the combustion of BTX under thermal oxidising conditions. As mentioned previously, methyl groups on an aromatic ring destabilise the resonance (compromise the aromaticity). This is in agreement with ASRL's findings with the relative ease of combustion for BTX following the order X>T>B. One might expect the first step in xylene and toluene destruction to be dealkylation (*i.e.* loss of the methyl groups). However, no benzene and/or toluene product was observed in ASRL's tests when toluene and xylene were added to the feed individually. Perhaps the dealkylation intermediate readily undergoes an alternative reaction pathway under thermal oxidiser conditions that does not lead to the corresponding aromatic. Nevertheless, the combustion of BTX has limited options:

- incomplete combustion to produce CO and H_2;
- complete combustion resulting in the direct formation of CO_2 and H_2O;
- or some combination of incomplete and complete combustion.

The net formation of CO in the lower temperature experiments demonstrates option 1 as a viable pathway for BTX destruction in ASRL's experiments as the only source for CO production was the BTX added to the feed. If the net CO production was resulting from the water-gas shift reaction, a continual increase in CO concentration with increasing temperature would have been observed. However, at 800°C, near complete CO conversion was observed in all cases. At lower temperatures, the production of CO from BTX in the feed outpaced the CO oxidation, which explains the negative CO conversions observed in this study.

If BTX destruction was only occurring through the incomplete combustion pathway, net H_2 production should also be expected when net CO production is seen at 600 and 700°C. However, the results show H_2 conversions just below zero at 600°C and in the positive range at 700°C. Based on the H_2 conversions measured in the blank tests, this observation cannot solely be explained by the reaction rate of H_2 oxidation being faster than that for CO. A plausible interpretation is that BTX destruction results in both incomplete (H_2) and complete (H_2O) combustion products for the aromatic hydrogen atoms. The above propositions for BTX combustion under thermal oxidiser conditions are summarised in equation 1.

$$BTX + O_2 \xrightarrow{500\text{-}700°C} CO + H_2 + H_2O \xrightarrow{O_2,\ 800°C} CO_2 + H_2O \quad (1)$$

Note that equation 1 does not encompass all the observations made in this work. The lower H_2S conversions in experiments with BTX present suggests that other destruction pathways involving H_2S as an intermediate may exist and H_2S could be added to the initial product slate formed in the 500-700°C range. However, at higher temperatures (>700°C) quantitative H_2S conversion was observed in both the low and high BTX concentration experiments.

Conclusions

Several conclusions can be made regarding the destruction of BTX under the conditions employed in this study:

- BTX conversion is enhanced with increasing reaction temperature and 700°C is the minimum temperature required for complete conversion of the aromatics;
- lower destruction is observed at higher BTX concentrations and flow rates (*i.e.* shorter residence time than 2 s with 3000 ppm);
- at lower temperatures, the presence of BTX in a tail gas stream has a negative influence on the oxidation of H_2S, CO and H_2;
- no dealkylation products were seen in the experiments investigating toluene and xylene.

The kinetic products of BTX combustion under thermal oxidiser conditions observed in this work were CO and H_2 and the final products were CO_2 and H_2O. To tie this into ASRL's previous studies, if a thermal oxidiser is being operated at a temperature to deal with CO oxidation, then the presence of BTX should not cause issue. However, as mentioned, BTX conversion is concentration dependent and if very high levels are present then perhaps higher temperatures and/or longer residence times would be necessary where mandated. ■

References

1. Greenwood N.N. and Earnshaw A.: "Chemistry of the Elements", (2nd ed.), Butterworth-Heinemann. ISBN 0-08-037941-9 (1997).
2. Dowling N.I., Huang M. and Clark P.D.: "The chemistry and kinetics of Claus tail gas incineration – Improving Incinerator Efficiency", ASRL Quarterly Bulletin, Vol XLV, No.2, pp. 21-55 (2008).
3. Dowling N.I., Li D.and Marriott R.A.: "The chemistry and kinetics of NH_3 destruction in the Claus thermal oxidizer, Alberta Sulphur Research Ltd. Quarterly Bulletin, Vol. LV No.1, pp. 23-44 (2018).
4. Dowling N.I., Huang M. and Clark P.D.: "Mechanisms of BTX conversion in the Claus furnace", ASRL Quarterly Bulletin, Vol XLV, No.4, pp. 3-12 (2009).
5. Dowling N.I., Huang M. and Clark P.D.: "The chemistry of BTX conversion in the Claus combustion furnace and strategies to improve hydrocarbon conversion, ASRL Quarterly Bulletin, Vol XLVII, No.4, pp. 30-44 (2011).

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Modular acid plant SAP250M

T. Schüller of Outotec provides insight into Outotec's strategic initiative to provide the sulphuric acid industry with a standardised modular sulphur burning sulphuric acid plant, based on Outotec's recent contract execution experience for a similar project in Central Africa.

SAP250M plant philosophy

Sulphuric acid process

The SAP250M modular sulphuric acid plant is based on the combustion of liquid sulphur and considers the double absorption/double conversion (DA/DC) process consisting of four catalyst beds (3+1) with the intermediate absorption tower designed downstream of the third catalyst bed. This configuration was selected to achieve high process efficiency and satisfactory environmental considerations.

For economic reasons and convenience for a project in contract execution, one common standalone sulphur melting, filtration and storage section is foreseen to service three SAP250M modular acid plants (see Fig. 1).

The advantage of multiple acid plant modules is that a proportion of acid production can be taken offline for operational as well as maintenance reasons, whilst maintaining some supply to downstream consumers. Availability of each modular acid plant is typically 330 production days per year, with the capability of the plant running safely and reliably as low as 40% of the plants' nameplate capacity of 250 t/d for extended periods of time.

Within each acid plant, approximately 11.5 t/h of superheated steam with up to 520°C and 3,000 kPa (absolute) can be generated alongside sulphuric acid with a concentration of 98.5 wt-%. Steam is routed to battery limits for consumption in client's plant complex as well as covering the required steam demands in the sulphur melting process. There is also the option that the modular plant can be configured to allow for SO_2 export, resulting in a subsequent decrease in acid production.

The basic modular configuration is designed to operate with process parameters within a certain range such as steam parameters, type and quality of water used for cooling and dilution, conversion rates (between approximately 99.7 to 99.9 %), as well as process gas export for further processing (SO_2 liquefaction units). Additionally, design values for atmospheric conditions, earthquake factors, wind load, plant elevation etc. have been considered to cover multiple scenarios to mitigate plant redesign.

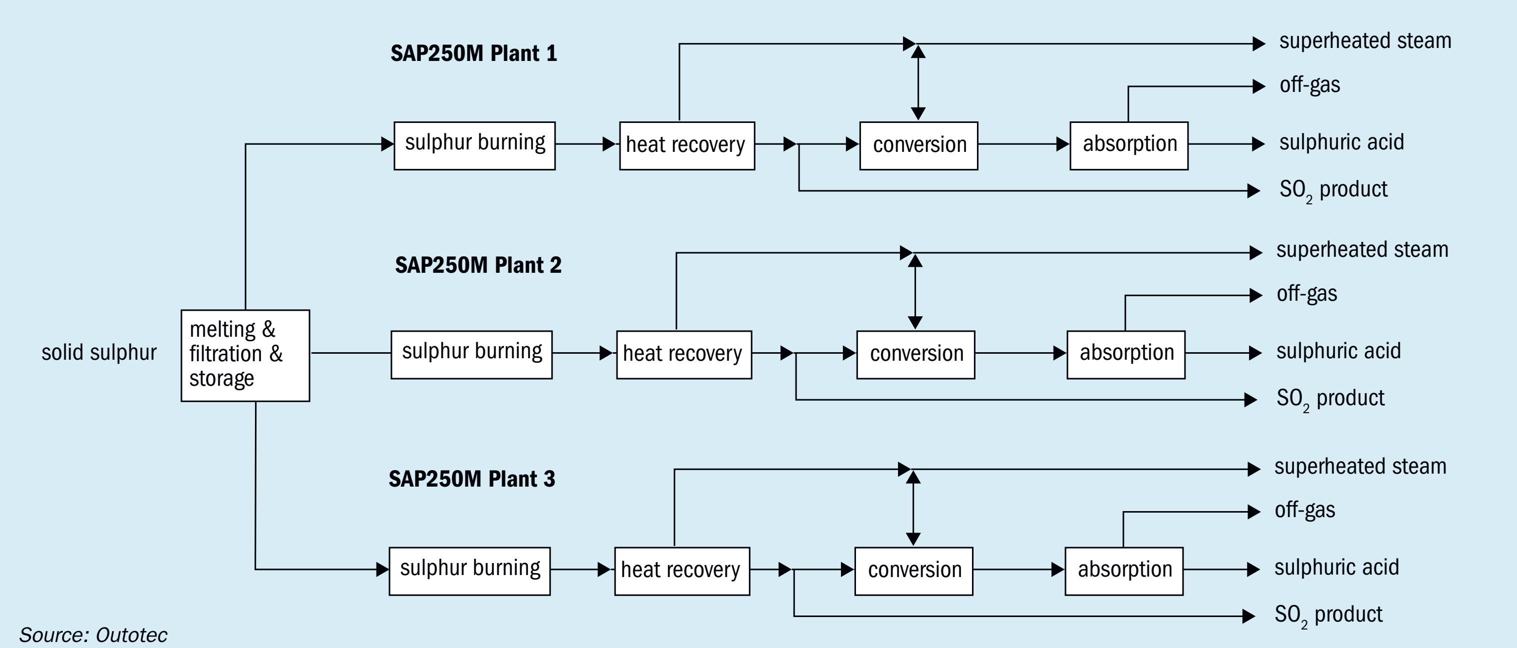
By adjustment of process parameters as well as catalyst type and quantity, the modular plant can be modified to client demands and local emission requirements.

Modularisation concept

Outotec's design philosophy for low capacity acid plants is based on the experience gathered with traditional plant designs of similar capacity, as well as the experiences gained from the recent contract execution for a project in Central Africa.

The plant consists of standardised process components (so-called 'modules'), which are pre-assembled in such a way as to optimise shipping/logistics, as well as significantly reduce time for the plant installation at site. Most modules match the dimensions of standard shipping containers, however larger modules need to be shipped as oversize equipment (so-called 'break bulk' cargo). These oversized

Fig. 1: **Block flow diagram of common sulphur melting and handling with 3 x SAP250M modular acid plants**



Source: Outotec

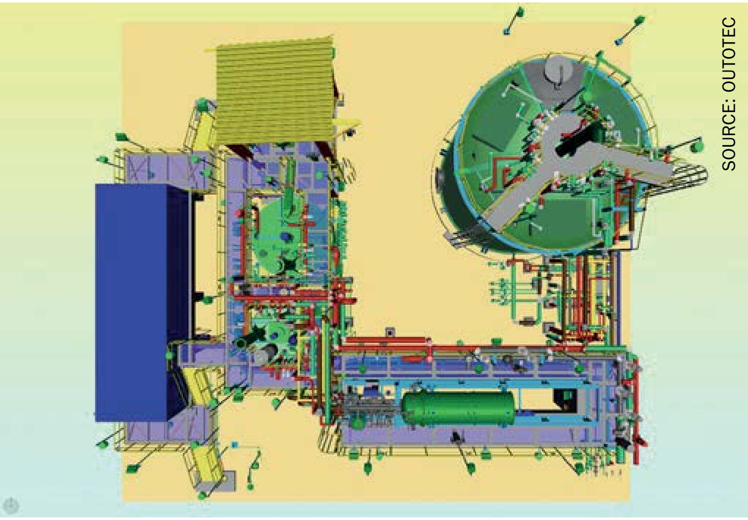


Fig. 2: Common melting section for 3 x SAP250M modular acid plants (24 m x 26 m) – plant layout.

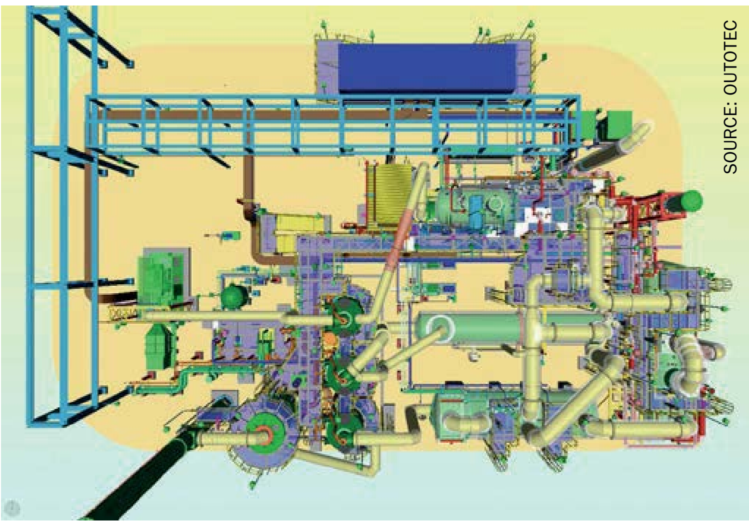


Fig. 3: SAP250M modular acid plant (30 m x 42 m) – plant layout.

modules have also taken into consideration dimensions and weight restrictions that would potentially limit road transport in the majority of jurisdictions.

Consideration of country-based site skill sets have also been assessed – for example the lack of artisans in certain countries allows the combustion furnace module to be shipped from the fabricator with its refractory lining installed, thus eliminating any refractory work at site. In such a case, the combustion furnace module (windbox, furnace including refractory and fired tube boiler) would require special transport, which would be assessed on a case-to-case basis.

While preassembled modular design usually means an increase of material weight, transportation and logistics cost, it results in lower installation efforts and ultimately decreased project delivery time as a balancing factor.

It is acknowledged that modularisation is not a common concept for acid plants associated with mining projects, however Outotec sees certain areas of the world where such a concept is beneficial to the customer, particularly at remote inland sites.

Conventional acid plants are normally tailored to highly specific demands of the customer and as such each plant design is unique. The modular concept is however designed to meet more generic plant requirements and it needs to be understood that customer specific requirements can only be accommodated to a certain degree.

If the standard modules are acceptable with little or only very minor modifications to the standard design, the engineering and subsequently plant capex cost is highly cost competitive.

Plant layout

Outotec has considered a standard layout configuration to limit re-engineering of the SAP250M. Minor rearrangement of the plant to meet customer space requirements can be considered. However, the implications to plant capex and delivery time will be impacted if significant reorientation is required.

Based on Outotec's significant experience in the industry, as well as the execution of the recent project in Central Africa, it is believed that the configuration considers most customer operational and maintenance based demands and as such fulfils most requirements of the industry.

The plant layout of the SAP250M is divided into the sulphur melting/filtration/storage section and the acid plant (see Figs 2 and 3). This allows the customer to locate the melting part close to the solid sulphur storage area.

The sulphur melting section layout was chosen to achieve easy access to the sulphur filter and to rotating equipment for maintenance activities. The layout in U-form reduces the length of piping to be installed on site, which is particularly relevant for the steam heated lines. The acid plant is then fed by a common steam heated sulphur line which can have branch-off to additional SAP250M acid plants.

The acid plant section layout was chosen to facilitate the installation of multiple SAP250M acid plants. It is considered, that all process and utility streams are routed along the shorter side of the SAP250M. This reduces the volume for the main pipe rack.

Within the acid section the total number of vessels was reduced in order to cut down the number of foundations as well as the length of ducting for less on-site installation. Outotec has taken into consideration the location of most instruments and dampers for easy accessibility within the relevant modules.

Individual modules

For the 250 t/d acid plant – the so-called "SAP250M" – the main modules are described in the following sections. Emphasis is directed at the technical solutions that have been implemented for key equipment.

In overview, Outotec have configured the plant based on:

- five modules in total for the sulphur melting and filtration section
- thirteen modules per acid plant

additional standard sea containers in which bulk materials such as ducts, piping, instrumentation, insulation and so forth are required to be transported to site.

Sulphur melting and filtration section

Irrelevant to the number of modular acid plants that will be installed in parallel, it is advised to feed the acid plants from one common sulphur melting, filtration and storage facility.

The capacity of a single melting and filtration facility is not critical to the module design. Practical considerations, such as regular cleaning effort of common sulphur filter, lead to significantly less opex and maintenance costs compared to sulphur filters in multiple trains.

It should however be noted that when more than one SAP250M acid plant is fed from a common melting facility the separate modules within this area are enlarged and would need to be considered as 'break bulk' cargo rather than standard sea container dimensions.

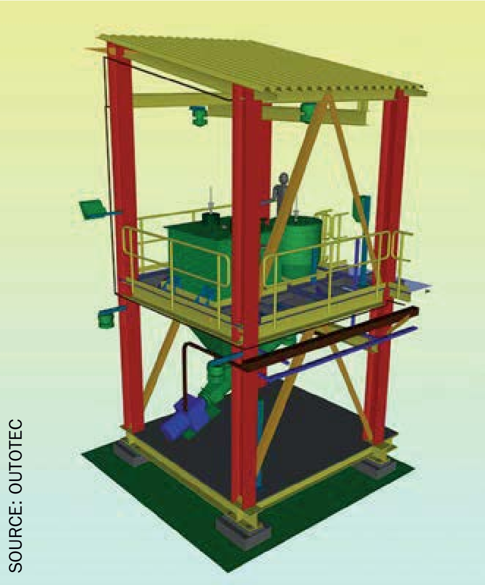


Fig. 4: Sulphur feed module.

Sulphur feed module

The sulphur feed module (Fig. 4) consists of a feed hopper, lime dosing and conveying system.

Solid sulphur is fed to the solid sulphur feed hopper via a payloader, direct from big bags or via on site conveying system, dependent on customer infrastructure and overall capacity of the sulphur melting facility. Instrumentation to control the external conveying system handling equipment can be installed without modifications to the standardised sulphur feed module.

The equipment is integrated into a common steel frame which is subsequently used to attach the access platforms at site. The complete module is located on concrete foundations, based on the site elevation requirements.

To accommodate the arrangement of the site sulphur bin, the lime dosing system and the screw conveyor can be separated from the melting and dirty sulphur pump tanks, which are installed on a common frame.

The individual components of the module are shipped preassembled and have to be assembled on site.

Melting module

The melting module (Fig. 5) comprises the melting tank, dirty sulphur pump tank and auxiliaries.

The prerequisite amount of sulphur is processed in a melting tank which is equipped with two internal heating coils and agitator for intensifying the heat transfer and prevent dirt from settling in the tank. Via an overflow line liquid sulphur flows to the dirty sulphur pump tank, whose contents is homogenised by an agitator. A submerged pump feeds sulphur to the downstream filtration module.

The dirty sulphur pump tank is used to prepare the precoating mixture for the sulphur filter in the sulphur filtration module, located downstream.

A structural steel frame around melting and dirty sulphur pump tank reduces installation work on site and supports the access platforms.

On site erection of vents, installation of heating elements, pumps, piping insulation and electric and insulation needs to be completed.

Filtration module

The sulphur filtration module (Fig. 6) consists of one horizontal leaf type filter, police filter, steam heated piping and utility piping. All items are installed on a common streel frame, which also acts as a part of the rail system for the sulphur filter.

The solid impurities are separated in the sulphur filter (horizontal leaf type filter) from the liquid sulphur. Particles that inadvertently pass the main filter will be captured in the downstream police filter.

Before the filtration operation commences, the sulphur filter needs to be precoated by circulating a precoating solution mixed in the upstream dirty sulphur pump tank, part of sulphur melting module.

To remove the solids from the process the sulphur filter is opened for cleaning. The filter cake falls into the compartment or container below the filter and can be removed by front-end loader.

This module is transported in an open top high cube sea container and is positioned onto its concrete foundations at site in a single lift.

The on-site concrete structure ensures drainage of liquid sulphur by gravity to the melting tank and provides enough clearance to access the area below for filter cake removal by payloader. Access walkways are installed directly on the foundation. Piping, electric connection, insulation as well as the filter elements are installed on site before the module is ready for operation.

Clean sulphur storage module

For storage of clean liquid sulphur, a cylindrical tank with internal steam heating elements installed from the top of the vessel has been selected for a 3 x 250 t/d acid plant. The tank is prefabricated and shipped in multiple segments, which must be welded on site. In this way the transport volume can be significantly reduced compared to shipping multiple individual smaller storage units.

For a single 250 t/d acid plant delivery, two horizontal storage tanks are foreseen.

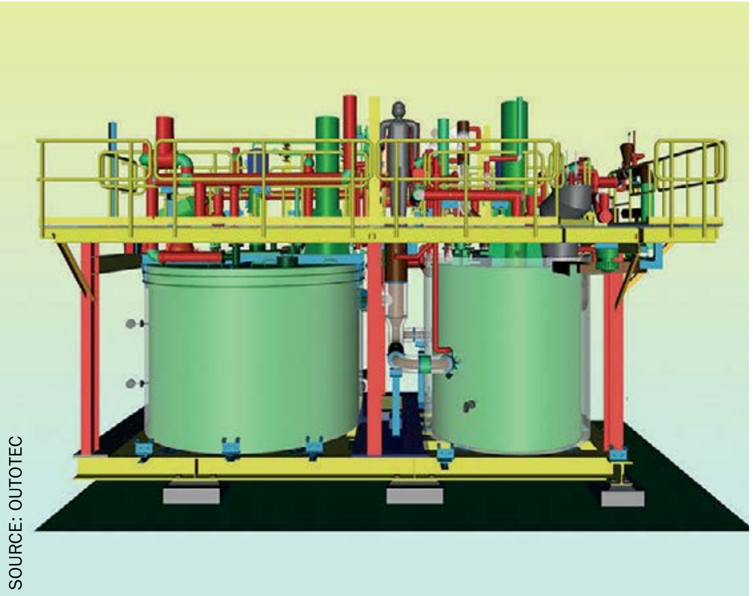


Fig. 5: Melting module.

Fig. 6: Sulphur filtration module at workshop.

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

Fig. 7: Sulphur combustion module

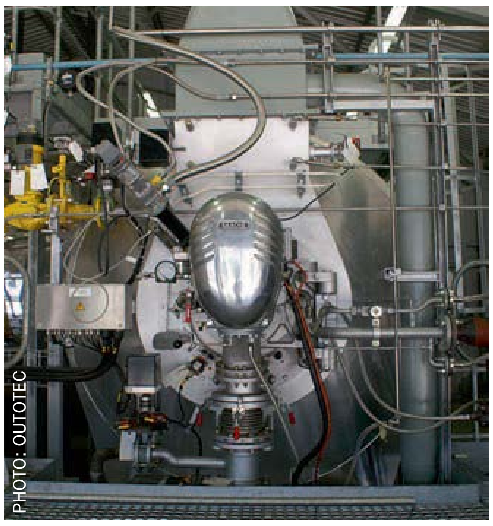
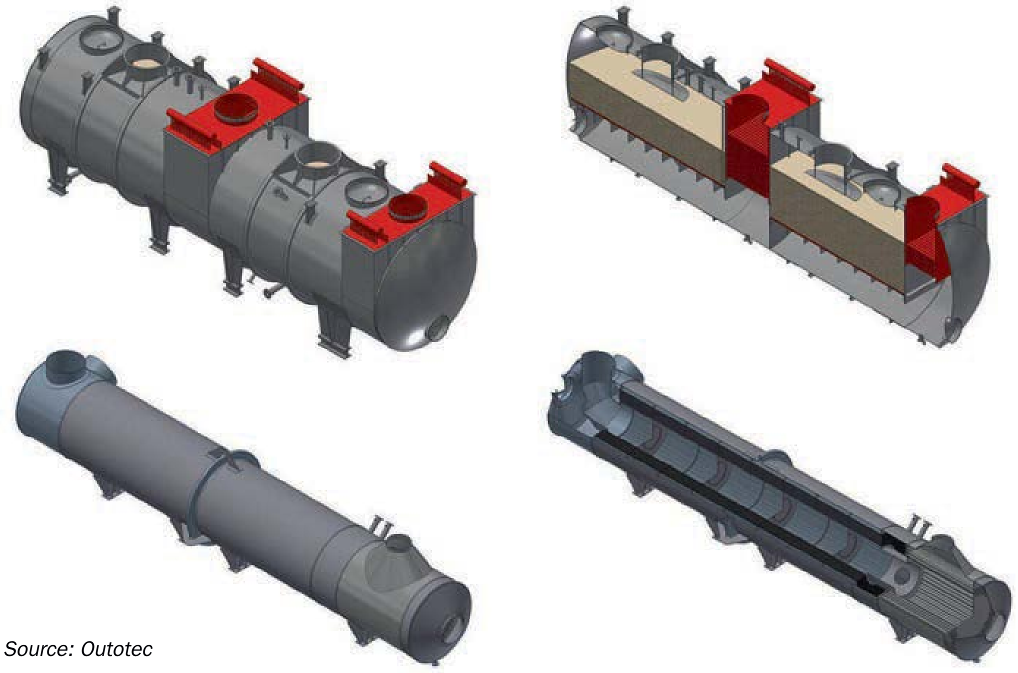


Fig. 8: View of the LURO burner on the combustion module.



Source: Outotec

Fig. 9: Converter 1 module (top) and CORD™ heat exchanger module (bottom)

Acid plant section

Sulphur combustion and waste heat boiler

For sulphur combustion, a LURO™ spinning cup burner, developed by Outotec and Saacke GmbH, is provided for atomisation of liquid sulphur. The highly turbulent atomising effect due to spinning cup design ensures swift and safe combustion of the sulphur and hence enables the design of very small furnace volumes with less refractory bricks on the inner layer. The sulphur combustion furnace is of horizontal design with adequate heat insulation to prevent corrosion due to potential dew point condensation of sulphuric acid.

For the waste heat boiler, Outotec has considered a fire tube type boiler with integrated steam drum.

To prevent direct radiation from the flame on the tube bank, the inlet vestibule is refractory lined. All refractory installation work is performed in the workshop.

This unit is the heaviest module and components are mounted on a common steel support structure. The steel structure serves as reinforcement for transport and as base for the boiler feed water system, which is installed on top of this module.

Fig. 7 shows a sulphur combustion module and Fig. 8 shows a view of the LURO burner.

Conversion

For the converter vessel Outotec took a unique approach by rotating the vessel into the horizontal position and dividing it into sections to reduce the transport height.

The group consists of two separate horizontal vessels each containing two catalytic layers. Converter 1 (Fig. 9) contains beds 1 and 2 as well as two superheaters. Converter 2 contains beds 3 and 4 plus one economiser. The materials of construction of both vessels ensure that there is no requirement for brick lining.

Boiler components are incorporated into the vessel, eliminating the associated shell, vestibules and ducting to simplify installation and maintenance. These components can be easily disconnected from each other to allow plant maintenance or relocation. The philosophy reduces the number of gas ducts and relevant expansion joints, insulation and support structures. With the elements located inside the converter, heat loss is also minimised.

For the cooling and re-heating of the process at the intermediate absorption tower, Outotec installed an adapted version of its patented CORD™ heat exchanger.

Drying and absorption tower modules

Drying tower (DT), intermediate absorption tower (IAT) and final absorption tower (FAT) are a combined tower design, with a first venturi stage and a packed bed absorption stage to allow for significant size reduction. Each tower is considered a separate module.

Gas passing through the venturi throat is co-current with the acid and achieves high absorption rates. Downstream of the venturi, further SO_3 respectively water absorption is carried out in the packing section, surrounding the venturi core tube with acid in counter-current flow.

The acid distribution systems in the packed bed stage (Fig. 10) are of special annular design fabricated from Outotec SX.

In the towers mist is generated by condensation. Removal of these particles is facilitated by wire mesh for the DT and IAT. High efficiency candle type filters are installed downstream of the FAT in a separate candle filter pump tower (Fig. 11) which provides sufficient space for the installation of the filters and acts as a common pump tank.

Fig. 10: Acid distribution in the packed bed stage of the venturi absorption towers.

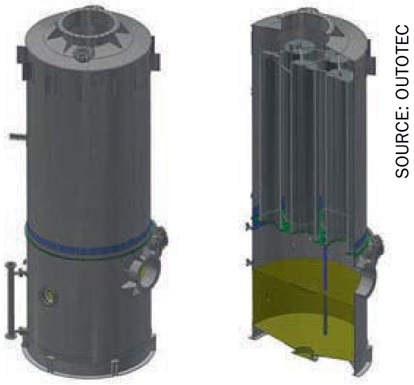


Fig. 11: Pump tower module with candle filters.

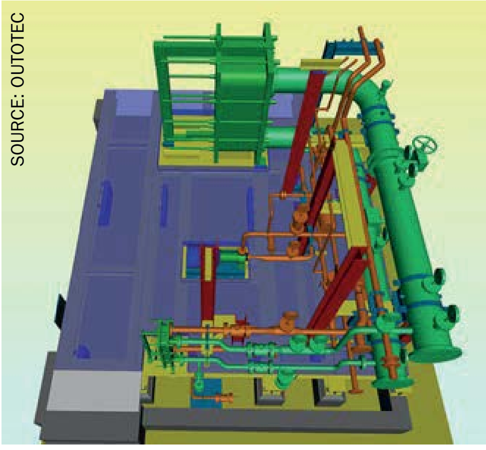


Fig. 13: Acid cooling and pump module

Fig. 12: Drying tower and absorption tower modules.

Modules for DT, IAT and FAT look very similar apart from the internals and their ultimate duty.

Material of construction of the towers is of stainless steel with some critical areas fabricated from Outotec SX. The sump of the towers is not used for acid retention, leading to reduced potential for corrosion in these areas. The venturi throat is brick lined which is installed in the workshop.

Fig. 12 shows drying tower and absorption tower modules.

Acid cooling and pump module

Acid cooling is performed by one plate heat exchanger for the circulated acid and one for product acid. Coolers are placed at ground level on a steel frame with gratings. Acid pump, dilution water station and cooling water system including piping (Fig. 13) are pre-installed on the frame prior being shipped to site.

Main blower module

Combustion air is drawn from the atmosphere into the plant through an air filter by the main blower. In the filter, dust particles are removed to prevent any contamination of downstream equipment.

Filtered air is conveyed by the main blower through the downstream acid plant. The flow rate is controlled by a variable speed drive. The blower with noise enclosure and silencer with filter are delivered on steel frames for easy installation on concrete plinths.

MCC/DCS

The low-voltage switchgear is executed as a motor control centre (MCC) and located in a pressurised and air-conditioned substation room. The Motor Control Centre (MCC) and Digital Control System (DCS) are installed and tested in a combined container split into two independent rooms. The container is installed at site on a reinforced concrete foundation.

Due to plot requirements and transport limitations, each acid plant and sulphur melting section has its own MCC & DCS container.

Construction concept

Civil works are performed by the customer/customer's local engineer according to Outotec foundation load requirements.

As already stated, units are assembled in boxed or base frames including lifting lugs, designed with respect to its centre of gravity. For transport reasons some equipment such as instruments, diluter, heating coils, superheaters, economisers as well as stairs, walkways and platforms, pipe and cable racks or supports and insulation are supplied separately and transported to site in standard sea containers.

In some modules, electric and instrumentation is installed, internally wired and terminated up to an onboard connection point.

Connecting piping systems are mostly of flange type and wherever possible and reasonable, systems are spooled and pressure tested.

With the exception of the stack the overall plant profile is kept low, thus the need for high/long reach cranage can be avoided.

Summary

The acid market is increasingly interested in the SAP250M plant concept developed by Outotec. The possibility to install a fully functioning acid plant in remote areas with reduced effort in engineering and construction compared to tailor-made solutions in this capacity range is of immense interest for consumers, where it is difficult and expensive to purchase acid due to logistics and reliability of supply.

The quality of equipment and material, safety concepts and the overall process parameters are of high European standards, covering stringent requirements regarding emissions and effluents.

The modular design concept provides an optimised schedule and mitigates technical and commercial risk of the overall project implementation. The use of standardised equipment and plant components enables fast delivery and installation at site, whilst ensuring high plant availability during operation.

Acknowledgements

Presentation Sulphur Conference 2018 Gothenburg "Modular acid plant development at Mutoshi DRC – an update" by Anne Mohsler, Outotec GmbH & Co. KG.

New plant design using modular SolvR® scrubbing system

G. Palmquist and **B. Blair** of DuPont Clean Technologies describe how a holistic plant design using a modular scrubbing system can optimise emissions, energy recovery and operating costs of sulphuric acid production.

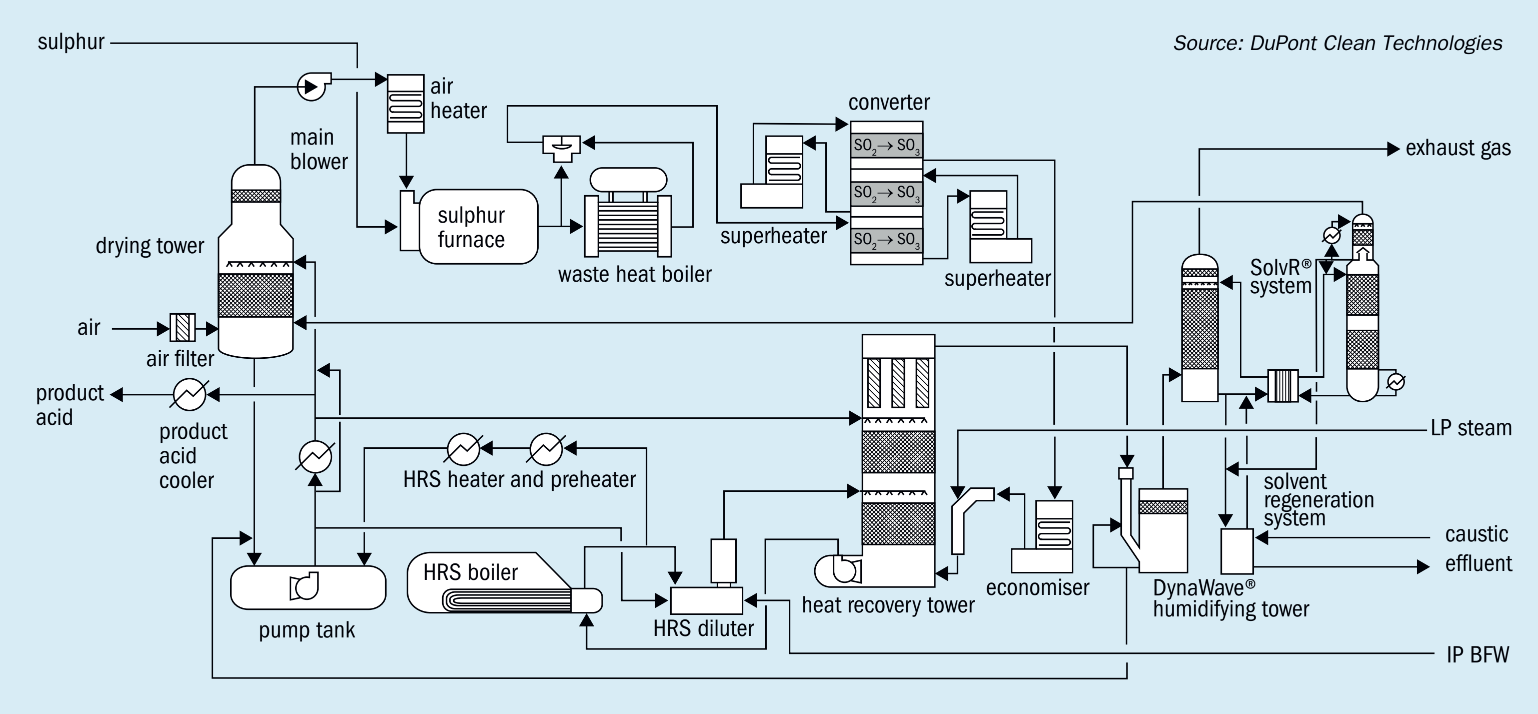
Conventional sulphuric acid plant flow schemes result in a complex web of equipment. When heat recovery systems and other technologies are added, the layout of the interconnected equipment becomes quite complicated. This is the natural outcome when systems are designed for their individual purpose rather than in an integrated way that aims to achieve efficiency and optimisation. The inclination for sulphuric acid plant operators seeking operations and productivity improvements is to invest in new technologies with constrained capex and operating budgets; this results in a myriad of trade-offs. They have to balance emissions, operability, maintenance and reliability. The net effect of this approach too often leads to a sub-optimal result.

For the past decade, this conundrum has been the driving force behind research at DuPont Clean Technologies. In order to avoid compromises on performance, operation, emissions, reliability and maintenance, DuPont Clean Technologies took a holistic approach to plant design. The result of the development work was the MAX3™ technology, a highly efficient integrated system consisting of a conventional single absorption sulphuric acid plant process with a heat recovery system (HRS™) and the MECS® SolvR® regenerative SO_2 scrubbing technology. This integrated design makes it possible to reduce equipment, lower operating costs, maximise energy recovery and still achieve best in class SO_2 emissions.

How does MAX3™ work?

When setting out to meet the challenge of addressing all the various sulphuric acid plant design needs with a single integrated solution, the focus was on developing a plant design that would achieve maximum profitability and emissions control but would also limit operating costs, recover more energy and result in lowest possible

Fig. 1: **MECS® MAX3™ flow scheme**



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SO_2 emissions. To do so, DuPont Clean Technologies designed a fully integrated single absorption MAX3™ flow scheme that combines a single absorption HRS™ plant with a modular MECS® SolvR® regenerative SO_2 scrubbing technology (see Fig. 1).

Energy recovery

MAX3™ incorporates a number of MECS® technologies to increase the production of high-value, high-pressure steam while also reducing cooling water consumption. The plant design achieves these results in a number of ways.

Energy recovery through MECS® HRS™

The MECS® HRS™ technology reliably recovers low temperature energy as intermediate-pressure steam of up to 10 barg from sulphuric acid plants to either generate electricity or replace steam produced by a fuel-fired boiler. By employing advanced alloy materials, the high concentration (>99 wt-%) strong acid circulating in the HRS™ operates at elevated temperatures allowing production of up to 0.5 tonnes steam/tonne sulphuric acid. The inclusion of steam injection in the system further improves heat recovery by upgrading excess low-pressure steam to intermediate-pressure steam.

Energy recovery facilitated by modular SolvR®

The MECS® SolvR® technology, first commercialised in 2014 at a sulphur burning plant in the United States, follows the same principles of unit operations as any regenerative SO_2 removal process. Tail gas from a sulphuric acid plant is adiabatically hydrated in a DynaWave® scrubber and flows into a countercurrent absorbing column, where SO_2 is absorbed into a circulating flow of solvent (see Fig. 2).

Clean gas exits the absorber at the top and the rich solvent is pumped to a stripping tower which removes SO_2 by steam stripping. SO_2 is recycled to the front end of the sulphuric acid process and lean solvent is pumped to the top of the absorbing tower. SolvR® solvent does not require unique stainless steel materials and is readily available at a much lower cost than other regenerative solvents used to remove SO_2. Steam consumption is also less than other regenerative processes. And while the SolvR® system is a net consumer of energy, steam injection can be used to closely integrate heat recovery between the SolvR® and the acid plant in a breakthrough way. Nearly the entire SolvR® system is supplied as a modular unit, with only the larger vessels (DynaWave® scrubber and absorbing tower) installed off-skid for larger installations.

The integration of the high-capacity MECS® SolvR® solvent in the MAX3™ design offers several benefits. The efficient removal and recycling of SO_2 by SolvR® makes it possible to switch sulphuric acid plants from double to single absorption, which not only eliminates an acid tower and cuts equipment costs, but also increases high-pressure steam production and keeps the plant's capital costs roughly at the same level as a typical double absorption plant with HRS™. Further optimisation and reconfiguration of the HRS™ and high-pressure steam systems provides a drastic improvement in high-pressure steam production while reducing intermediate-pressure steam and maintaining cooling water use at or below that of a conventional HRS™ plant.

Single absorption energy recovery improvement

By switching to a single absorption plant, it is possible to operate without a low temperature economiser, eliminating the need to reheat gas from an interpass absorption step.

Shifting energy from intermediate to high pressure steam

By reconfiguring the HRS™ to heat high-pressure boiler feed water, energy shifts from intermediate pressure to high-pressure steam. At the same time, the increase in operating pressure of the deaerator improves both intermediate- and high-pressure steam production. Additional energy can be transferred to high-pressure steam by using an air heater on the combustion air for the sulphur furnace. The heat source may be intermediate- or high-pressure steam, or hot boiler-feed water, but in each case the net effect is increased high-pressure steam production.

Low temperature energy recovery with SolvR®

Integrating low-temperature energy recovery from the SolvR® overhead condenser reduces both cooling water and low-pressure steam use. As with any low temperature heat, the supply temperature of the treated water limits the amount of energy recovered.

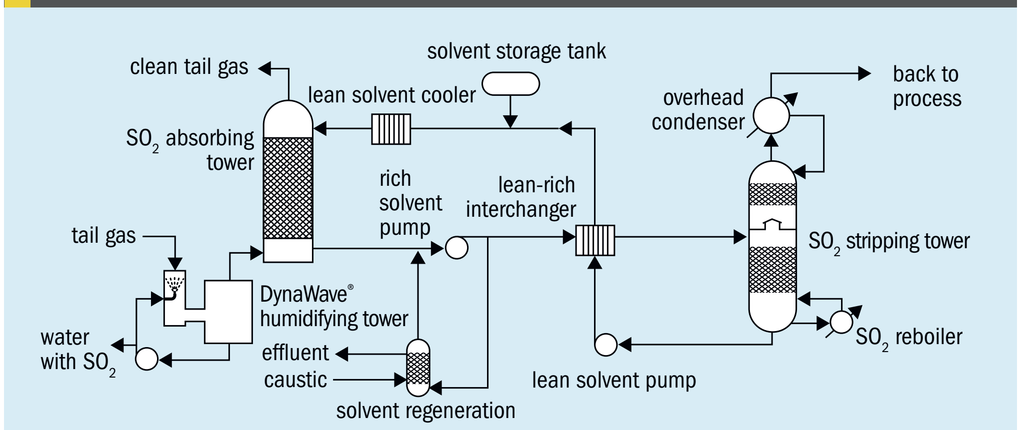
Additional heat recovery options with MAX3™

Depending on specific site requirements, the MAX3™ technology makes it possible to have two additional energy recovery options. First is the option of installing a back-pressure turbine drive using high-pressure steam to meet the low-pressure steam requirements of the SolvR® system (as low as 0.2 barg). Secondly, any excess low-pressure steam generated by this turbine or by other on-site means can be upgraded to intermediate-pressure steam through the addition of SteamMax™ to the HRS™ to raise the steam injection rate from approximately 40% to as much as 90%. Fig. 3 shows a flow sketch of a turbine-driven main gas blower that produces 2 barg steam – inside the acid plant battery limits – which can feed the SolvR® and can be upgraded to either intermediate pressure steam or high pressure steam in the HRS.

SteaMax™ LP steam upgrade

Steam injection, a MECS® technology first commercialised more than fifteen years ago, offers an economically advantageous method for maintaining concentration control in the HRS acid system. A portion of the water required for concentration control is provided through the steam injection vessel, and the remainder is provided in

Fig. 2: **SolvR® process**



Source: DuPont Clean Technologies

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Fig. 3: **MAX3™ heat integration**

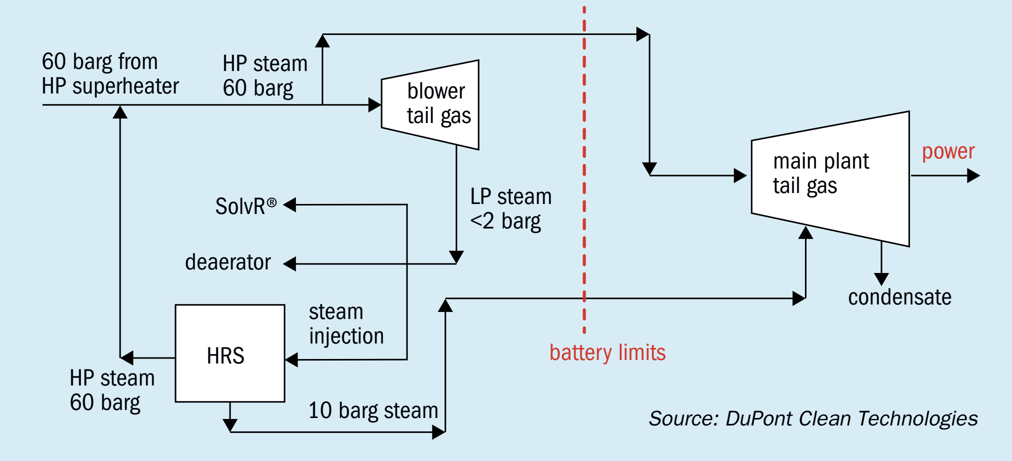
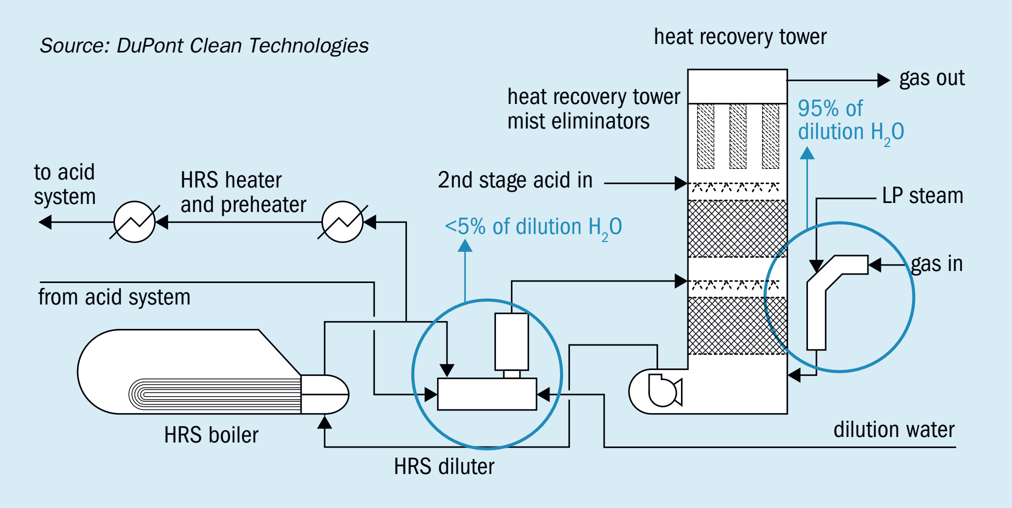


Fig. 4: **SteamMax™**



the HRS diluter. Low pressure steam is injected into the process gas in a steam injection chamber upstream of the heat recovery tower. Since the overall enthalpy of the water fed to the HRS is higher when steam is used, the latent heat from condensation boosts generation of HRS steam compared to HRS designed without steam injection. Effectively, steam injection upgrades low pressure steam that would otherwise be vented to atmosphere.

About eight years ago, DuPont Clean Technologies introduced a step change improvement to steam injection called SteaMax™ (see sketch in Fig. 4).

The SteaMax™ HRS design uses an even higher steam to liquid water ratio for dilution, approaching operation with little or no liquid water for dilution. This configuration multiplies the enthalpy effect of conventional steam injection, allowing most plants to realise gains in absorption heat recovery of 20-30% over a conventional HRS with steam injection. But the most important benefit of SteaMax™ could not be realised until the development of SolvR®. Combining these two technologies led to MAX3™.

High pressure steam production with MAX3™

Incorporating each of these energy enhancements with MAX3™ results in high pressure steam production of up to 1.55 tonnes steam/tonne of sulphuric acid at approximately 45 barg and 400°C. This increase in high-pressure steam production cuts intermediate pressure steam production from the HRS™ to 0.29 tonnes steam/tonne of sulphuric acid at approximately 10 barg saturated.

Operating and capital costs with MAX3™

The MAX3™ process offers substantial operating cost benefits when compared to a traditional double absorption sulphuric acid plant with HRS™. Overall energy recovery (sum of high and intermediate pressure steam rates) is slightly higher due to the choice of single absorption. In addition, the proportion of heat recovered as high-value, high pressure steam is significantly higher (up to 20%) than in a conventional plant while intermediate-pressure steam is reduced by 40%.

At the same time, utility costs for a MAX3™ plant are low compared to those of a double absorption HRS™ plant while achieving nearly undetectable SO_2 emission requirements. A MAX3™ plant will have lower electricity and caustic uses with equivalent or lower cooling water use.

The capital cost of a MAX3™ plant is roughly the same as for a conventional plant. Although elimination of double absorption equipment cuts initial capital costs this is offset by additional heat recovery equipment and the use of the modular SolvR® system.

SO_2 emissions with MAX3™

In a MAX3™ plant, the use of SolvR® for selective removal of SO_2 from exhaust gases makes it possible to reduce SO_2 emissions to almost zero. The removed SO_2 is concentrated to 100% (saturated with water) and subsequently returned to the upstream process or condensed as a standalone high-value product. This proprietary, improved absorption solvent is non-toxic, non-corrosive, very stable and robust, and offers lower operating costs than competitive technologies.

The solvent forms a stable complex at relatively low temperatures (25-40°C). Thus, sulphur dioxide is efficiently removed from exhaust gases and then released when the solvent is heated to a temperature of about 100-110°C. The SolvR® solvent also has a high absorption capacity. In the SO_2 absorbing tower a small flow of solvent efficiently removes the sulphur dioxide from the flue gas. Heat stable salts are readily removed from the solvent and do not interfere with the solvent's ability to absorb SO_2 from the flue gas.

SolvR® is capable of removing sulphur dioxide from gas feed concentrations of 300 ppmv to 50 vol-% in the inlet gas. Typically, the system will reduce emissions below 20 ppmv. If lower emissions are required, stripping steam can be increased incrementally and emissions can be lowered to below 10 ppmv. In the first commercial unit, operating data has shown that SolvR® is capable of reducing emissions to about 1 ppmv with higher solvent flows to the SO_2 absorbing tower.

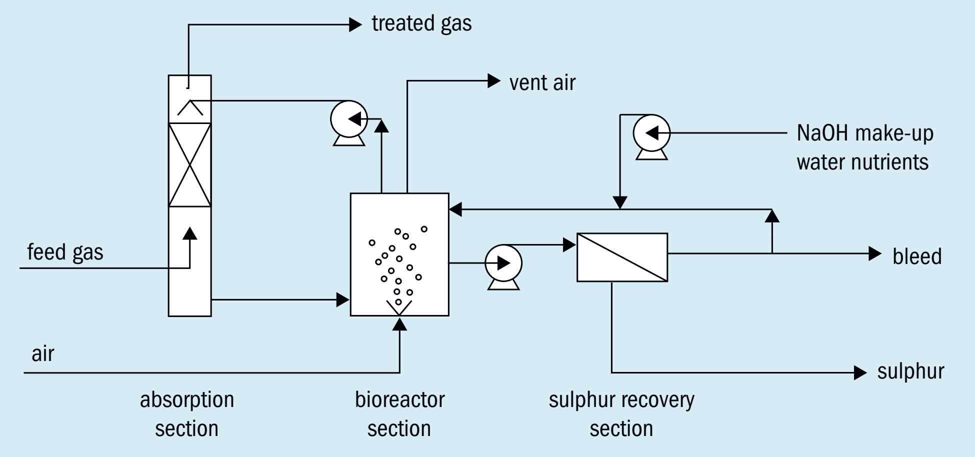
Conclusion

The optimised MAX3™ plant design sets out to improve the profitability of sulphuric acid plants by addressing three critical aspects: energy recovery, emissions reduction, and cost.

Biological SRU under turndown conditions

XTO Energy's East Texas natural gas operations operate a skid built biological desulphurisation unit (Thiopaq O&G) to treat amine acid gas from an AGRU unit which removes CO_2 and H_2S from sour gases gathered from approximately 800 wells. It was found that the SRU showed continued strong performance in dealing with significant turndown of the feed gas flow rate (30% of design) and sulphur load (17% of design). **J. Klok, R. de Rink, G. van Heeringen, J. Timmerman** of Paqell B.V. and **P. Shaunfield** of XTO Energy Inc. discuss the operational data and lessons learned from recent years of operation.

Fig. 1: **Standard biological desulphurisation process scheme with the absorption, regeneration and sulphur recovery section**



Source: Paqell

Natural gas has been processed and used as a clean, reliable energy source for decades. Hydrogen sulphide (H_2S) in natural gas is undesired and its bulk removal traditionally takes place by the application of physicochemical processes such as the AGRU-Claus-TGTU train. These processes typically operate at high temperatures which results in more complex design schemes and are therefore expensive, particularly in small-scale applications. In addition, for lean acid gases with an H_2S content of less than 30 mol-%, process modifications are required to secure thermal stability of the Claus burner, such as co-firing, oxygen enrichment and/or a complete acid gas enrichment (AGE) processing step.

The biological desulphurisation process Thiopaq O&G uses microbiological sulphide oxidation. As this takes place at ambient temperature and pressure and uses a simple process line-up, it is more cost-effective than the AGRU-Claus-TGTU train for lean acid gas processing[1,2]. It is the most applied modern sulphur recovery technology with over 270 plants built world-wide in biogas applications and in the oil and gas industry since 1992.

This article discusses experiences and findings at a biological desulphurisation plant in operation for XTO Energy's East Texas natural gas operation under turndown conditions.

Biological desulphurisation

The market for H_2S removal can be divided into small-scale, small-to-medium scale and large-scale plants. For small-scale applications several types of scavengers are available on the market, with operating costs of over $5000 per long ton of sulphur removed[3]. Large scale applications are typically served by Claus/TGT units, which are fed by acid gas downstream amine extraction.

Over the years, several technologies have been developed to address the technology gap in the low to medium scale sulphur range. Examples are wet scrubbing processes such as the Lo-Cat® and Sulferox® processes[3]. These technologies convert H_2S to elemental sulphur using solutions containing chelated iron. The downside of these processes is the continuous requirement of stabilising chemicals and addition of catalysts, which is the main driver for opex[4]. As an alternative, the biological desulphurisation process, the Thiopaq O&G technology, uses a mixture of sulphide-oxidising bacteria as catalyst. These organisms are naturally occurring, and reproduce by using the released energy from the oxidation of sulphide to elemental sulphur. Therefore, after the initial seed at start up, no further addition of fresh catalyst is required. In addition, the formed sulphur has hydrophilic properties, and therefore does not require any stabilising agents.

The biological desulphurisation process consists of three simple, integrated steps: absorption, regeneration and sulphur recovery (see Fig. 1). In the first step, feed gas is counter-currently contacted with alkaline solution. H_2S is absorbed and converted to bisulphide (HS^-), thereby consuming alkalinity of the process solution. The process can handle gas streams with a pressure ranging from 1 to 80 bar(g) and is not restricted to a minimum or maximum H_2S concentration. For high pressure gas streams, a flash vessel is included. The following overall reactions (chemical equilibria) occur:

H_2S absorption

$$H_2S + CO_3^{2-} \rightarrow HS^- + HCO_3^- \quad (1)$$

CO_2 absorption

$$CO_2 + CO_3^{2-} + H_2O \rightarrow 2\ HCO_3^- \quad (2)$$

The second step takes place in the bioreactor, in which the bisulphide-rich solution is mixed with air. Here, the bacteria oxidise the dissolved bisulphide to elemental sulphur. This regenerates the process solution (alkalinity is restored). The overall reactions in the bioreactor are given by:

Sulphur formation

$$HS^- + ½\ O_2 + HCO_3^- \rightarrow S^0 + H_2O + CO_3^{2-} \quad (3)$$

CO_2 stripping

$$2HCO_3^- \rightarrow CO_2(g) + CO_3^{2-} + H_2O \quad (4)$$

In the third step, a slipstream of the process solution, containing sulphur as suspended solids, is directed to the sulphur recovery section. The sulphur is dewatered, yielding a sulphur cake of about 65-70 wt-% solids. Typically, the sulphur-dewatering unit is a decanter centrifuge. The clear liquid is collected and recycled back to the bioreactor, while a small part of this stream is bled from the system for conductivity control and by-product removal.

As the Thiopaq is a biological process, it can deal with large fluctuations in flow rate and composition of the feed gas. In general, lower gas flow rates are no problem for the Thiopaq O&G technology, i.e. the H_2S removal efficiency is not affected by a turndown in the gas flow rate. The turndown in sulphur load is determined by the capacity of the bioreactor. In general, per bioreactor the conversion efficiency is not affected up to 30% turndown, i.e. no increase is expected in chemical usage per tonne of sulphur. At lower turndown, the conversion efficiency will slightly decrease, resulting in relative higher operational costs (costs per tonne of sulphur processed). In case the facility requires a large turndown in the sulphur load, a multiple bioreactor line-up is more beneficial. For example, a facility with three identical bioreactors can still efficiently operate at 10% turndown of the sulphur load.

The biological desulphurisation process is characterised by the following differentiators[1,5,6]:

- **Low environmental impact:** e.g. H_2S removal efficiency >99.99% and no free SO_2;
- **Lower capex:** less equipment count i.e. no requirement of burners and reboilers compared to conventional AGRU+Claus+TGTU. Regeneration and sulphur recovery sections operate at atmospheric pressure and ambient temperature.
- **Simplicity:** less operator manning levels. Produced bio-sulphur is hydrophilic and behaves like a stable suspension without clogging.
- **Safety:** no free H_2S downstream the absorber, ambient temperatures in the entire system, atmospheric pressure in bioreactor and sulphur recovery section.
- **Small footprint**
- **Uptime:** over 99% availability

Plant history

XTO Energy is a Fort Worth based energy producer engaged in the acquisition, development and discovery of long-lived oil and natural gas properties in the United States, with activities concentrated in Texas, New Mexico, Arkansas, Oklahoma, Kansas, Wyoming, Colorado, Alaska, Utah and Louisiana. Focusing on properties located in the major producing areas of the United States, XTO increases production through low-risk means, including the reduction of operating costs and development drilling. As a result of growth activity, XTO required an economical solution for sulphur recovery from gas streams in small to medium quantities[7]. In 2009, ExxonMobil agreed to acquire XTO Energy Inc. and the acquisition was finalised in June 2010.

In 2007 it was decided to start a new project to treat natural gas in Teague. In this facility, all natural gas from about 800 wells is gathered at one treating facility (Trend Gathering & Treating, Teague, also known as XTO3) and processed with an AGRU unit to remove all sour components from the natural gas. Subsequently, the amine acid gas is processed with the Thiopaq O&G technology to convert H_2S to elemental sulphur. The Thiopaq O&G unit was designed for an acid gas stream of 2.43 million scf/d, with an H_2S concentration of 2.5 mol-%. Hence, the design sulphur load is 9.3 long t/d. Details of the design basis for the Thiopaq O&G unit are shown in Table 1.

H_2S removal from the AGRU acid gas takes place in two parallel absorbers, both 50% of the capacity, for reasons of weight, costs and higher operational flexibility. The treated gas (designed for <50 ppm) is directed to a thermal combustion unit. As XTO3 was skid built, the bioreactor section contains five parallel bioreactors, each with a design capacity to form 1.9 long t/d of sulphur. The bioreactors were shop fabricated and the material of construction is GFRP. The sulphur is removed from the process solution using a decanter centrifuge. While the cake is disposed to landfill, bleed water is treated to remove sulphur particles and subsequently injected into depleted wells. Fig. 2 shows a picture of the treating facility.

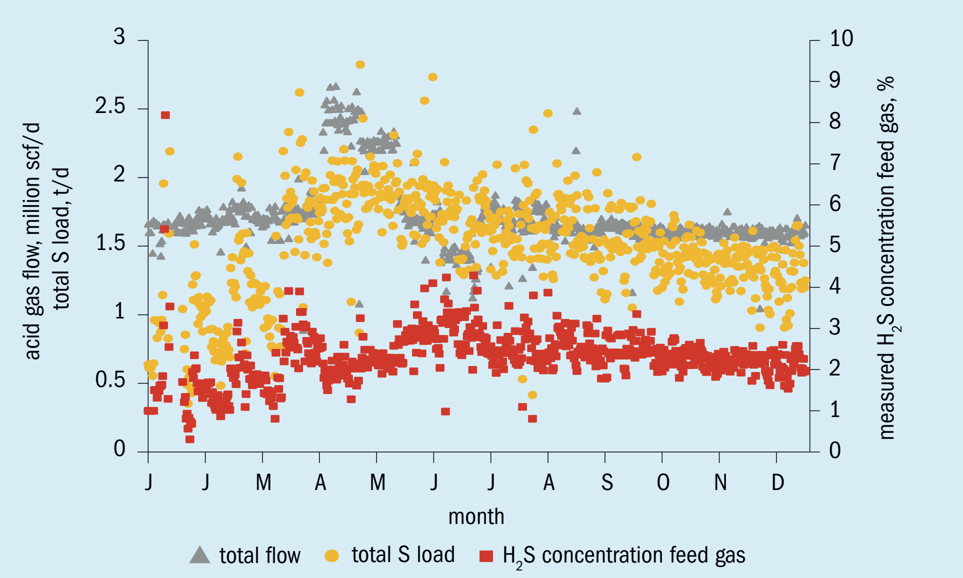
Table 1: **Design basis of XTO3 and typical dry gas analysis after start-up**

	Design basis	Dry gas analysis
Flow feed gas, million scf/d	2.43	1.5
Pressure feed gas, psia	19.6	23.7
Total sulphur load, long t/d	9.3	1.4
H_2S, mol-%	9.1	2.5
CO_2, mol-%	83.5	96.6
CH_4, mol-%	0.19	0.26
C_2H_6, mol-%	<0.01	0.01
C_3H_8, mol-%	<0.01	<0.01
C_4^+, mol-%	<0.01	0.66
H_2O, mol-%	7.1	-

Source: Paqell

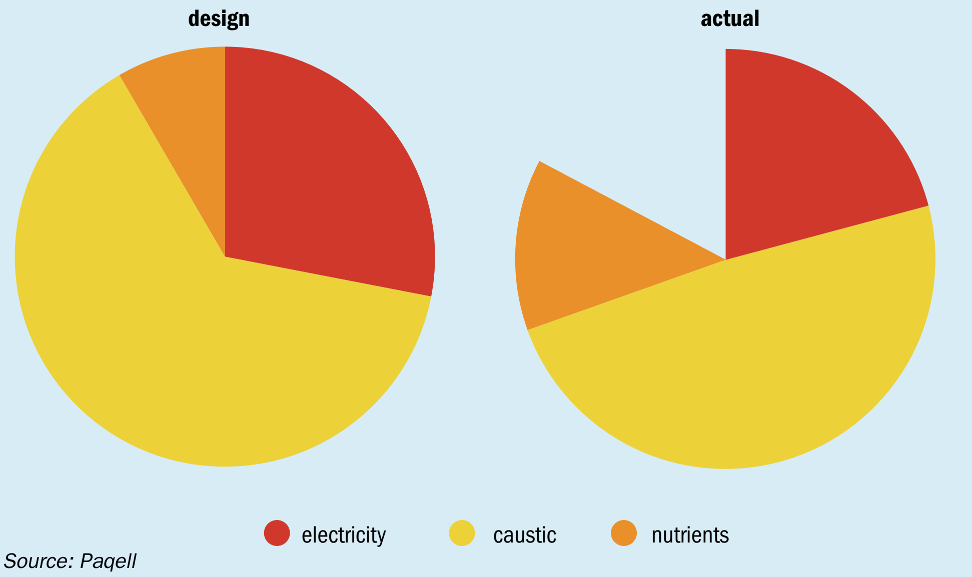
Fig. 2: Treating facility, showing the absorbers (A), bioreactors (B) and sulphur recovery building (C).

Fig. 3: **Variations in inlet H_2S concentrations, feed gas flow and sulphur loads to the Thiopaq O&G unit**



Source: Paqell

Fig. 4: **Comparison of consumable costs between design criteria of consumptions per processed ton of sulphur and actual data under tundown conditions over a year**



Source: Paqell

Turndown operation

After start-up of XTO3, the overall sulphur load to the SRU was lower than anticipated, as both the feed gas flow and the H_2S concentration in the acid gas were lower than designed for. Initially, sulphur loads were 4.0 long t/d. In addition, the C6+ content of the feed gas was higher than anticipated in the design phase. The detailed design gas composition is shown in Table 1. Since start-up, the availability of the Thiopaq O&G system has been >99%. Furthermore, the sulphur loads have dropped over time. Fig. 3 shows typical sulphur loading data to the Thiopaq O&G unit for one year of operation. The sulphur load to the Thiopaq O&G over the whole period was 1.5 ± 0.4 t/d sulphur, with variations between 0.5 and 3.5 t/d of sulphur. Hence, the average sulphur load was approximately 1.6 t/d, which is 17% of the design. Therefore, only two out of five bioreactors were in operation, i.e. per bioreactor, about 0.75 t/d of sulphide is converted to elemental sulphur. Despite the turndown operation and the variations in sulphur load, the gas is always treated within the permit of environmental legislation. The H_2S concentration in the treated gas is continuously monitored with an online UV detector, which shows significant interference with C6+. Therefore, an extra offline gas analysis was performed, showing that the H_2S concentration in the treated gas was always well below the design criteria of 50 ppm (i.e. 24.5 ± 0.8 ppm).

The operational costs (opex) of the process have been extensively monitored over time. The opex mainly consists of caustic dosing to compensate for loss via the sulphur cake, nutrient dosing to secure growth of the bacteria and electricity use. Fig. 4 shows a comparison of the actual consumptions per ton of sulphur with the design consumptions. It can be seen that both electricity and caustic consumptions per ton of processed sulphur are lower than anticipated in the design. The reduced consumption of electricity is mainly the result of the relative low requirement for air. Since the sulphur load is lower than design, less air is required to provide sufficient oxygen to the bacteria. The lower caustic consumption can be explained by low by-product formation (i.e. sulphuric acid). Due to the operation in only two of the five bioreactors, the maximum turndown per bioreactor is ~28% of design, which is still sufficient to limit by-product formation. In contrast to caustic and electricity, the nutrient consumption per ton of sulphur is higher than anticipated in the design. This can be explained by the variations in the feed gas composition and the sulphur load. To secure process stability with the considerable and sudden fluctuations in the feed gas, some extra nutrients are dosed to the system to secure the availability of sufficient catalyst (i.e. bacteria).

System start up

Besides operation at turndown conditions, other challenges for XTO3 are power failures. In the region of Teague, the power grid is mainly above ground and therefore relatively vulnerable to e.g. weather conditions. As a result, occasionally the plant power supply is interrupted and processing of natural gas is not possible. As a result, the biological desulphurisation system is shut down. In recent years, several power failures struck XTO3. From these failures, the following has been learned:

- At all shutdowns, no H_2S escaped from the process during shut down, which can be explained by the absence of free sulphide in the process solution.
- Restarts of the system are done within minutes, after which gas processing could be continued instantaneously, since no heating or time consuming start-up procedures are required. Due to the nature of the catalyst and process, bacteria will immediately start to oxidise sulphide when sulphide is present in the solution.
- The consumption of nutrients and caustic was not affected by the power failures, i.e. when restarting the system, no extra caustic, water or nutrients need to be supplied to the system.
- Biological activity was found to be unaffected by the power failures.

Conclusions

In this paper, the performance of a biological desulphurisation unit (Thiopaq O&G) at XTO Energy's East Texas natural gas operations has been studied. It was found that turndown nor power supply failures to the system did not affect the treating of sour gas streams.

It has been shown that XTO3, operated at 17% of the original design S-load, can deal with decreased levels of H_2S in the feed gas and overall lower feed gas flows than design. Based on the flexible, skid built design of the biological desulphurisation unit at XTO3, the plant is well able to deal with turndown operation while securing design criteria for consumables per ton of sulphur.

The unique aspect of the biological desulphurisation process is its catalyst, a mixture of sulphide-oxidising bacteria. These organisms are naturally occurring and multiply using the energy from the oxidation of sulphide to elemental sulphur. The main benefits of the catalyst in comparison to a traditional catalyst are: i) the biocatalyst continuously reproduces while traditional catalyst is subjected to degradation and hence, continuous replenishment is required and ii) the catalyst in the biological process can adjust to varying process condition and is therefore not affected by turndown; i.e. less sulphide entering the system will typically result in lower growth rates, but still guarantees the complete oxidation of dissolved sulphide. Hence, turndown and or power failures of the system will not affect the treating of sour gas streams. ■

References

1. Lee K., Bowerbank G. and van Heeringen G.: "Thiopaq O&G bio-desulphurisation; an alternative recovery Technology," GPA, Edinburgh (2013).
2. Klok J.B.M., van Heeringen G., de Rink R., Wijnbelt H., Hauwert P. and Bowerbank G.: "Techno-economic impact of Thiopaq-SQ, the next generation of the Thiopaq O&G process for sulfur removal," SOGAT, Abu Dhabi (2017).
3. Echt B., Leppin D.P.E., Mamrosh D., Mirdadian D., Seeger D. and Warren B.P.E.: "Fundamentals of low-tonnage sulfur removal and recovery," LRGCC, Norman, Oklahoma, (2017).
4. Kolar M., Roberts B., Osgood S. and Echt W.: "Coso case study: 22 years of reliable sulfur removal," in LRGCC, Norman (2017).
5. Jacques M. and Köning-Adolph A.: "Sulphur management for an unconventional gas-condensate field," *Sulphur* no. 368, pp. 37-41 (Jan-Feb 2017).
6. Shanghani P.: "Stranded no more – turning rich sour gas to profits using bio-desulfurization technology," GPA GCC, Kuwait (2019).
7. O'Brien M., Wentworth C., Lanning A., Engert T. and Benschop A.: "Shell-Paques® bio-desulfurization process directly and selectively removes H_2S from high pressure natural gas – start-up report," in LRGCC, Norman, Oklahoma (2007).
8. G. van Heeringen and J.H. van Dijk, "Shell-Paques desulphurisation process matured into breakthrough technology," Touch Briefings (2008).
9. Klok J.B.M., de Rink R., van Heeringen G. and Wijnbelt H.: " Thiopaq-SQ: the SRU for lean acid gases" *Sulphur* no. 370, pp. 50-53 (May-Jun 2017).
10. Janssen A.J.H., Meijer S., Bontsema J. and Lettinga G.: "Application of the redox potential for controlling a sulphide oxidizing bioreactor," Biotechnol. Bioeng., vol. 60, no. 2, pp. 147-55, (1998).

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ISSN: 0039-4890

Design and production:
JOHN CREEK, DANI HART

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

BCInsight

Published by: BCInsight Ltd
China Works, Unit 102,
100 Black Prince Road,
London SE1 7SJ, UK
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