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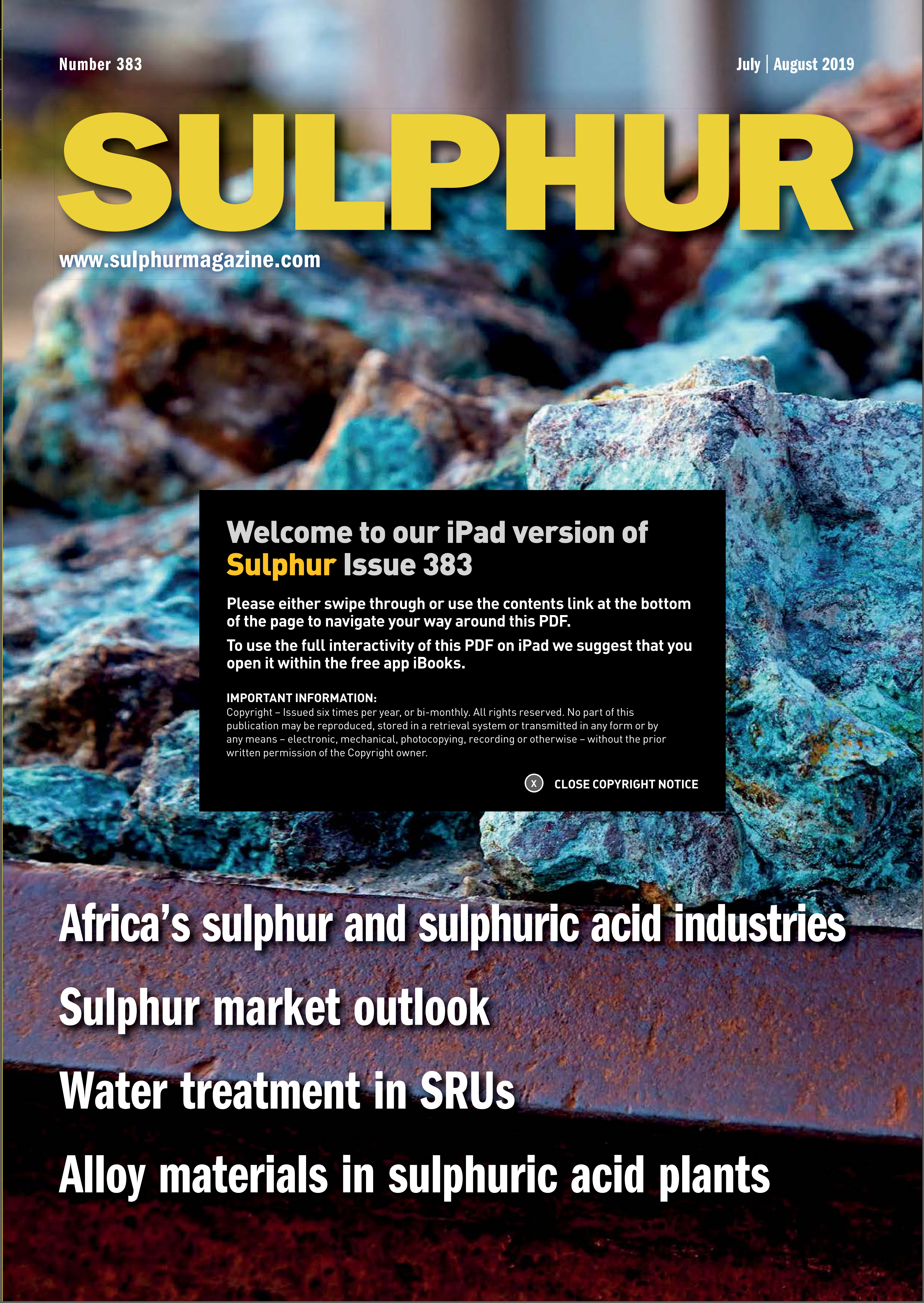

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Africa's sulphur and sulphuric acid industries

Sulphur market outlook

Water treatment in SRUs

Alloy materials in sulphuric acid plants

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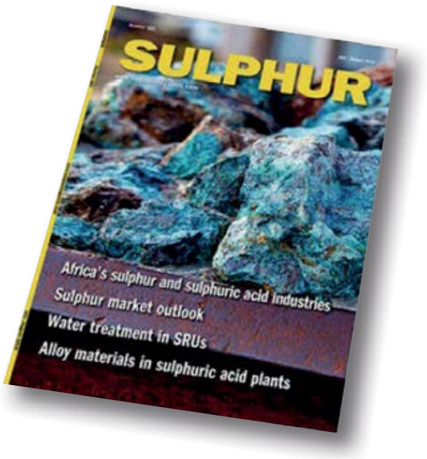
Published by: BCInsight

Editorial

All that glitters



> **"Phosphate rock has remained the mainstay of phosphorus production ever since.**

This year – probably – marks the 350th anniversary of the discovery of phosphorus – in truth no-one is quite sure, but it's the best guess. We owe its discovery to a man about whom much is also uncertain; Hennig Brand. Born in or around 1630, his origins are uncertain; he may have been apprenticed as a glassblower, although his wife later said he had come from money and served as an officer during the Thirty Years War. What is more certain is that he manged to inherit or acquire a small fortune, and that after the war he became an alchemist, trying to search for the so-called Philosopher's Stone; the secret of artificially creating gold.

The science in his method amounted to little more than noticing the golden colour of urine and inferring that it was somehow connected with gold. By the 1660s he was heating residues from boiled-down urine on his furnace until the retort was red hot, when glowing fumes abruptly filled it and liquid dripped out, bursting into flames. What he had done was reduce sodium ammonium phosphate with carbon to produce phosphorus vapour, which then condensed and then re-oxidised back to phosphate.

Brand noticed that if he kept the liquid away from air, it solidified into a white solid, which gave off a pale green glow. He called this in Greek *phosphoros* – 'light bringer', and was sure that he was on the track of the Philosopher's Stone. However, "all that glitters is not gold," as Shakespeare wrote, and after six more years of experimenting, he finally admitted defeat in his quest for gold, realising instead that he had discovered something new and completely different, at which point he began selling his method to other alchemists. By 1680 the great British chemist Robert Boyle had met Brand and begun refining the method of production, as well as mixing phosphorus with elemental sulphur to produce matches.

Over the 18th century, the raw material for production of phosphorus moved – perhaps fortunately – from urine to bone ash (a source of calcium phosphate), and finally in the 19th century first to bird/bat guano deposits on tropical islands such as Christmas Island, and then phosphate rock deposits. Phosphate rock has remained the mainstay of phosphorus production ever since, first using electric arc heating to break it down and then, as the contact process for the production of sulphuric acid increased the latter's availability and decreased its cost, sulphuric acid treatment of phosphate rock became the standard method for extracting phosphate.

As one of the key building blocks of life, phosphorus is a crucial nutrient for plants, and via them animals and humans. Demand for sulphuric acid for the extraction of phosphate from rock now represents more than half – perhaps 55-58% – of the sulphuric acid industry's output.

Hennig Brand may not have discovered gold. Indeed, far from making himself rich, his experimentation is said to have burned through his own fortune, his first wife's dowry and – when he remarried a wealthy widow – most of her money as well. However, 350 years on, his discovery has gone on to become one of the most important in chemistry, and one that still indirectly touches all of us today.

Richard Hands, Editor

Price trends

MARKET INSIGHT

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

SULPHUR

Global sulphur prices have yet to improve from a stable to soft footing since October last year through to June. The downward pressure from downstream processed phosphates has been a major driver for the continued stagnancy in market sentiment.

In the Middle East, monthly prices for June were posted at rollovers and minor decreases – a reflection of the weak to stable tone in the market. Muntajat announced its June Qatar Sulphur Price (QSP) at $102/t f.o.b., a rollover on May. The producer's monthly tender for 35,000 tonnes loading in July was awarded at $101/t f.o.b. Expectations were for July to see a slight decrease as there has been little to indicate bullish sentiment from producers. State owned ADNOC in the UAE set its price at $102/t f.o.b. Ruwais for liftings to the Indian market – a $3/t drop on a month earlier. Over in Kuwait, KPC set its June price at $101/t f.o.b. Shuaiba – a drop of $1/t on its May price.

In terms of negotiations for the third quarter, Middle East producers were in early stages through June, but initial indications were for potential drops on the second quarter range set at $80-104/t f.o.b. due to weak fundamentals and sustained low pricing in recent months. There remains a question mark over whether offtakers would look to reduce contracted volumes this quarter, due to healthy stock levels at major end users.

On the supply front in the region, additional volumes are still expected to emerge from late 2019 and through 2020 with the planned start-up of the Clean Fuels Project in Kuwait. Production from the project would lead to increased exports out of the country. Iranian output continues to ramp up this year, with the progress at the South Pars gas project stages adding fresh supply. Logistical issues at ADNOC's sulphur loading operations in Ruwais, Abu Dhabi are expected to persist through to August. Only one sulphur loading berth being operational during this time. Market estimates are for at least 200,000 tonnes of sulphur to likely to be out of the market due to disruptions loading sulphur and delays as a result.

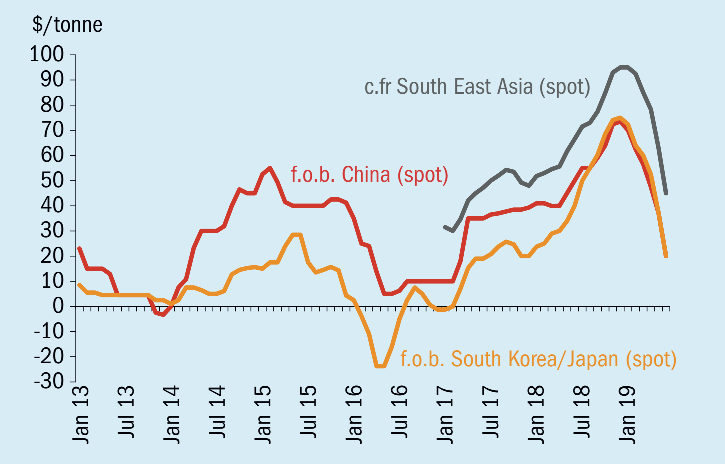
The main demand growth for sulphur in the coming months is expected to be from Africa. The short term focus will be on third quarter contract discussions. Once these conclude, we would expect to see Moroccan consumer OCP enter the spot market. The recent sulphur loading issues in the UAE may lead to a ramp up in requirements for spot volumes for the buyer, a supportive factor for the market. So far this year Argus estimates OCP is set to receive 2.91 million tonnes of sulphur at the ports of Jorf Lasfar and Safi. As further stages of the processed phosphates hub advances, increased volumes of sulphur will need to be procured. Meanwhile earlier reported disruption at Foskor's fertilizer operations in South Africa were heard to be improving slowly in June, on the back of labour disputes, financial issues and maintenance turnarounds. Demand for sulphur in the DRC is expected to rise in the outlook with the start-up of a new sulphur burner at Glencore's Kamoto Copper Company's (KCC) site.

Over in Asia, sulphur stocks at the major ports have been building and reached close to 1.9 million tonnes in June – a level not seen since 2017 and a market bear for the short term outlook. The stock build up has kept many buyers on the sidelines and reluctant to enter the market. Stocks may remain in the hands of traders for some time due to the stagnancy in market pricing. Spot prices have continued to erode in recent months, dropping to $90-117/t c.fr at the end of June. Decreases are likely on the high end of the range in the coming weeks based on the lack of positive demand drivers and ample stocks.

Sulphur imports in China have been on the rise through 2019 thus far following the drop seen in 2018. Supply from Iran has increased significantly – up by 118% year on year in the first five months of the year to 547,000 tonnes – due to sanctions on Iranian exports. As a result, supply from the UAE and Saudi Arabia has eroded. Volumes from Qatar have increased meanwhile, totalling close to 700,000 tonnes.

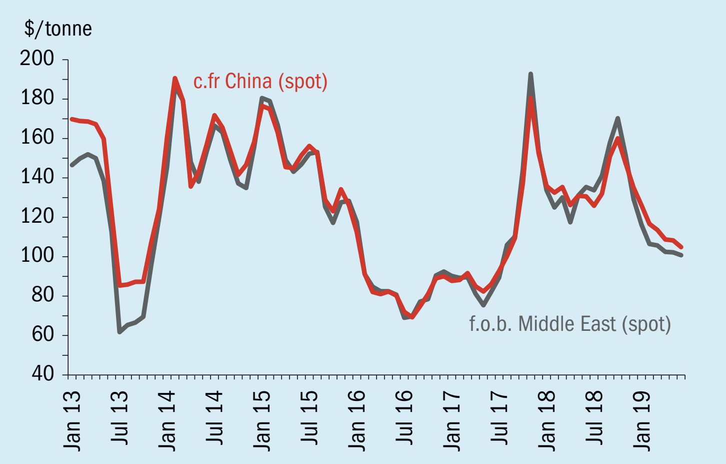
Indian buyers entered the market following the spate of maintenance turnarounds that kept buyers comfortable. PPL awarded a tender for a 40,000 tonnes cargo for arrival in early July in the mid/high $110s/t c.fr. Spot prices in the country were pegged at $115-120/t c.fr at the end of June – unchanged for several months. All eyes remain on the China market to see if prices drop further, which would potentially put pressure on any new business in India. The ongoing outage of the Sterlite

Fig. 1: **Monthly average sulphuric acid prices**



Source: Argus Media

Fig. 2: **Monthly average sulphur prices**



Source: Argus Media

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Tutocorin smelter in Tamil Nadu continues to be a supportive factor to the market balance. The development of the Indian monsoon will be closely watched in July as this will assist in assessing the outlook for sulphur demand in the country.

North American sulphur prices have been subject to the same trends seen in the international markets. Vancouver spot prices have eroded down to $93-97/t f.o.b. this year and have remained in the range since April. In company news, HJ Baker acquired Oxbow Sulphur – including facilities in Canada and the UK. HJ Baker operates sulphur processing facilities on the West Coast US, with the move set to place the company on an increasing global footing.

SULPHURIC ACID

Sulphuric acid prices have been dropping for months, with prices slipping further in June once again reflecting the recent slowdown in downstream demand before reaching a point of stability. In NW Europe, prices dropped by $25/t down since April to $30-40/t f.o.b. for spot exports. There is speculation a floor may have been reached now with indications demand may tick up due to fresh enquiries. Contract discussions for Q3 were underway with no deals reported concluded at the end of June. On the domestic front in Europe, rollovers were heard targeted on the supply side – due to the more stable footing that is expected in the short term outlook. Over in Central Europe supply disruption was heard at a major sulphur burner and smelter in Poland, leading to a boost in spot enquiries in the region.

There have been hints of fresh demand emerging in Latin America for August shipments particularly for the Brazilian market. On recent spot pricing, there has been price erosion – dropping to $62-72/t c.fr in June – down by around $30/t on April levels. The main obstacle to a Brazilian price recovery is limited prospects for the phosphates market recovery in the short term.

Small volumes have been sold into Chile to cover the shortfall in demand from recent arrivals and contracts. Deals have been noted concluded around $70-80/t c.fr Chile in June, reflecting around a $40/t drop on two months earlier. On the import front Chile imported 289,000 tonnes of acid in April, by 45% year on year. This brought January – April arrivals to 1.4 million tonnes, reflecting a 44% increase on a year earlier. Expectations are for imports to ease during the second half of the year, with restarts at Codelco's smelters easing the deficit. Meanwhile a two week strike at Chuqicamata impacted production.

Smelter acid production in China continues to rise in 2019, with Argus estimating an additional 5.8 million tonnes of capacity due to be brought online during the year. The upward trajectory in production poses major questions for the outlook in the acid market. In 2018, China moved from being a net importer of acid to a net exporter. Thus far in 2019 exports have remained strong. However the recent price decline has led some Chinese producers to retreat from the market with limited deals noted in June. Offers were still heard for cargoes loading through July and August and will test achievable prices. The price range in June was assessed at $15-25/t f.o.b. – in line with pricing in Northeast Asia. Major sulphur-based acid producer Two Lions is planning a maintenance turnaround at one of its lines from 20 July through until the end of August.

In January – May 2019 China acid exports totalled a record 991,000 tonnes – up by more than three times in the same period a year earlier. This sets the tone for exports to exceed the level seen in 2018 at 1.2 million tonnes for the whole year. So far in 2019 Chile remains the leading market for exports, with significant volumes also booked for Morocco and India at 230,000 tonnes and 123,000 tonnes respectively. Small volumes have also been shipped to Namibia and countries in Southeast Asia. Due to the rise in local supply as well as slow downstream markets, we have also seen a significant drop in China imports of acid – down by 40% year on year in the first five months to 238,000 tonnes. South Korea remains the leading supplier, followed by small volumes from Japan and Taiwan.

Major phosphates producer OCP in Morocco continues to import significant volumes of merchant acid as demand ramps up at its expansion at the Jorf Lasfar hub. The leading supplier in 2019 is China, with trade on this route expected to be dominant as Chinese acid producer Two Lions previously agreed to supply OCP with around 400,000 tonnes in 2019. ■

Price indications

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

Cash equivalent	February	March	April	May	June
Sulphur, bulk ($/t)					
Adnoc monthly contract	108	108	103	105	102
China c.fr spot	133	135	118	115	118
Liquid sulphur ($/t)					
Tampa f.o.b. contract	109	109	88	88	88
NW Europe c.fr	130	130	110	110	110
Sulphuric acid ($/t)					
US Gulf spot	100	105	105	95	95

Source: various

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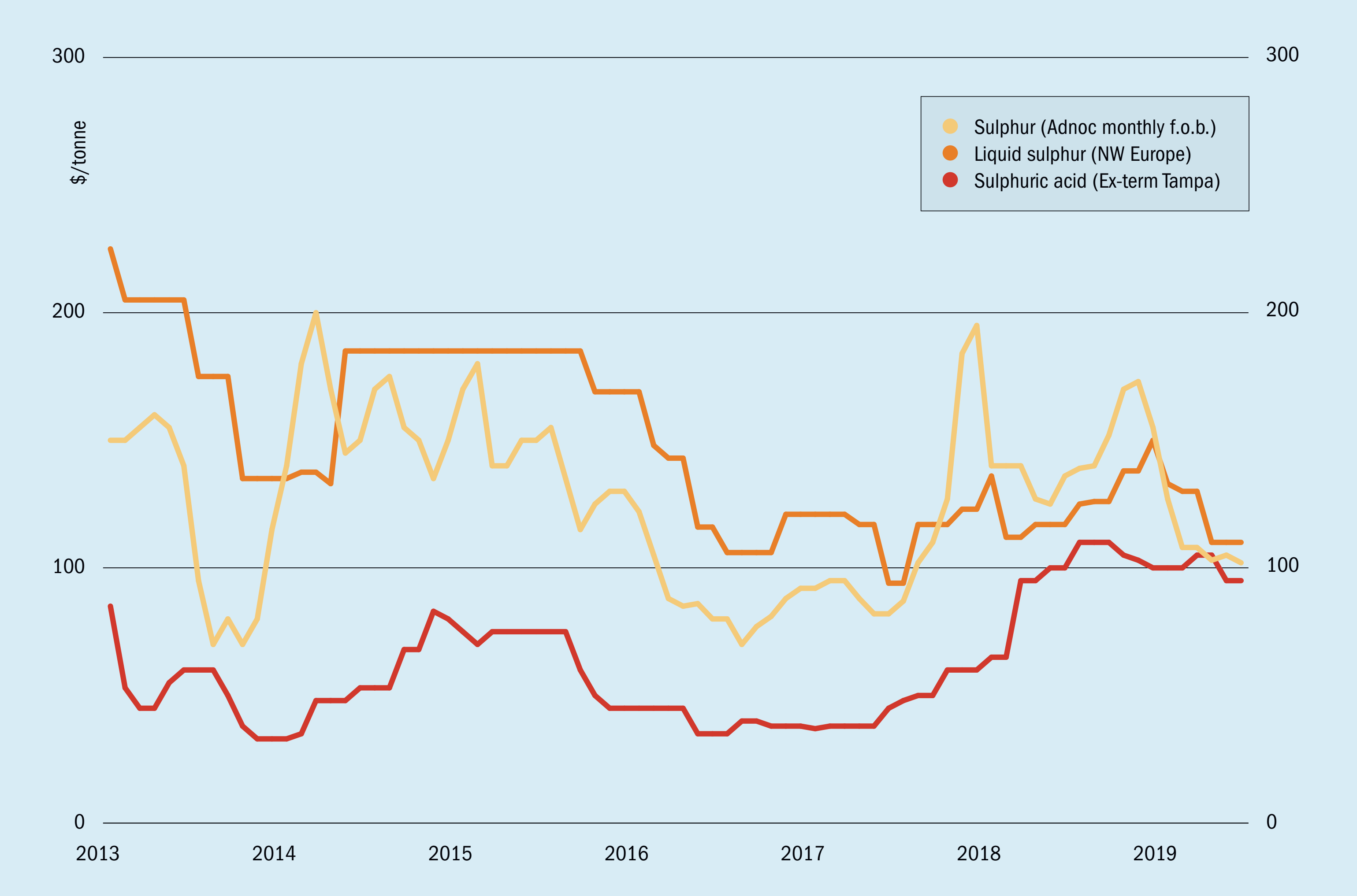
Market outlook

Historical price trends $/tonne



Source: BCInsight

SULPHUR

- The leading driver of sulphur demand is the processed phosphates market – a positive shift in market sentiment will likely help to prop up sentiment in sulphur. Phosphoric acid contracts were agreed at decreases in Morocco – setting the tone for a softer market.
- China domestic sulphur production continues to rise with additional capacity expected online in 2019/2020 – raising questions on how this may impact import requirements. The rise in sulphur port stocks is a bearish factor for the short term outlook.
- Tunisian sulphur consumer GCT is set to agree up to 250,000 tonnes of sulphur under third quarter contracts, with settlements yet to be heard.
- The start-up of the Indian monsoon will be closely watched, providing direction on sulphur consumption and supply, with potential for delays to hamper market sentiment.
- **Outlook:** Stability is likely in the coming weeks in the spot market but contract negotiations are likely to yield a drop in pricing due to the lack of support from demand. Looking ahead, additional supply is set to enter the market in 2019/2020 creating further competition in the export market. The main market to watch will be the phosphates sector – with any recovery to provide a boost to raw material pricing and uptake. However, uncertainty remains for this possibility and the outlook remains soft. Due to the tighter balance in NW Europe, molten contract prices are expected to be rollovers.

SULPHURIC ACID

- Demand prospects from Latin America: with demand stirring in the region, this could provide some relief in the coming months – however the lacklustre processed phosphates market remains a major downside factor that could limit market pricing recovery in Brazil.
- Indian acid production at Vedanta's Sterlite Tuticorin smelter remains down, a supportive factor for the Asian market and should keep Indian imports healthy.
- Ongoing weakness in the elemental sulphur market remains a market bear but any stability and potential for recovery could support acid pricing in the outlook.
- The return of local production in Chile following prolonged maintenance outages may slow import demand in the latter part of the year.
- Japanese acid exports declined in January – May 2019, down by 8% year on year to 1.27 million tonnes on the back of turnarounds and limited demand.
- **Outlook:** Global acid prices may have reached a floor, with potential to see stability in the short term. An uptick in demand in Latin America may support pricing but the downstream markets may need to see meaningful recovery before raw materials improve. Exports from China have been a major market bear and a slowdown in the second half of the year could help with market stability and pricing.

Sulphur Industry News

CANADA

Oil sands production forecast to be 1 million barrels up by 2030

Canadian oil sands production is set to enter a period of slower annual production growth compared to previous years. Nevertheless, total production is expected to reach nearly four million bbl/d by 2030 – up 1 million bbl/d from today, according to a 10-year production forecast by business information provider IHS Markit. IHS expects average year-on-year supply additions to be below 100,000 bbl/d in the coming decade. By contrast, growth over the current decade regularly averaged additions in excess of 150,000 bbl/d. Transportation constraints such as a lack of adequate pipeline capacity and the resulting sense of price insecurity in western Canada have weighed on new large scale incremental investments in the oil sands, said Kevin Birn, vice president, IHS Markit – who heads the Oil Sands Dialogue.

"Large scale oil sands projects take two, three, four or more years to be brought online and so the reality of a slower pace of investment and growth in the Canadian oil sands is taking shape," Birn said. "Yet, ironically the call on Canadian heavy sour crude oil – the principal export from the Canadian oil sands – has never been greater as the rapid deterioration of Venezuelan output tightens the supply of heavy sour crude globally."

Future growth will mostly come from existing projects and facilities as opposed to new projects, according to the forecast, which anticipates 40% of the rise in oil sands production to 2030 will come from ramp-up of projects in construction or recently completed. Nearly one-quarter of the growth will come from projects that are on hold but where some construction or site clearing has already begun and debottlenecking of existing operations. Less than one-third of anticipated growth is expected to come from "new projects," IHS Markit says.

With a few exceptions, western Canadian supply available for export is generally exceeding pipeline takeaway capacity even with the completion of Enbridge Line 3 until additional pipeline can be brought online; the latter likely sometime in 2022. In the meantime, crude-by-rail remains critical for ensuring market access.

The cost to construct a new oil sands project is anywhere between 25 percent and a full one-third cheaper than in 2014, the report says. Deflation in capital costs was a factor. But reengineering efforts such as simplifying project designs, building for less, and more quickly constructing and ramping up production has also played a major role in the reductions. The costs associated with the operation of oil sands projects have fallen even more dramatically. Operating costs for both oil sands mining operations with an upgrader and steam-assisted gravity drainage (SAGD) facilities fell by more than 40% on average from 2014 to 2018. Increased reliability; reducing facility downtime and increasing throughput was the biggest factor in the cost savings. These cost improvements have lowered the breakeven oil price for new oil sands projects from $65/bbl for West Texas Intermediate (WTI) crude to the mid-$40 per barrel range. Likewise, an oil sands mining project without an upgrader required a near-$100 per barrel breakeven price in 2014 compared to around $65 per barrel in 2018.

CHINA

Sulphur emissions control demonstration

Haldor Topsoe says that a demonstration plant for its now Preferential Oxidation Catalysis (POC) solution will be commissioned later in 2019. The catalyst removes hydrogen sulphide from viscose plant emissions as sulphur which can be made into sulphuric acid and reused as an essential raw material in the viscose production process. The new technology can selectively treat different sulphur compounds in order to more efficiently remove hydrogen sulphide from emissions, while retaining the carbon disulphide that is reused in the viscose plant. In addition, unlike traditional scrubbing, POC does not consume costly sodium hydroxide or produce waste water which is troublesome to dispose of.

The innovation was developed and tested in the laboratory and at a small-scale industrial plant in collaboration with Birla Cellulose of the Aditya Birla Group, the world's leading viscose manufacturer. The aim was to capture sulphur from exhaust gases for reuse in the closed-loop viscose production system. Topsoe says that the next step is building a large-scale demonstration plant in China together with Zhongtai Group in connection with a viscose plant in the Xinjiang province.

"We are very enthusiastic about testing this concept because the existing sulphur management technologies have expensive shortcomings when it comes to treating lean off-gases from viscose production. With the demonstration plant we expect to validate that this new solution cuts cost, secures efficient reuse of carbon disulphide and reduces sulphur emissions," says Mr. He, President Assistant, Zhongtai Group.

Sinopec targeting 10 million t/a of low sulphur fuel next year

Chinese energy giant Sinopec says that it has set a target of producing 10 million t/a of low sulphur fuel by 2020 to meet the growing market demand resulting from upcoming IMO regulations. The company will expand its production capacity to 15 million t/a by 2023. From January 1, 2020, Sinopec will start supplying low sulphur fuel at all major ports in China and more than 50 key overseas ports. Sinopec claims the commitment will contribute towards sulphur oxide emissions reductions of 600,000 t/a.

AUSTRALIA

WorleyParsons reorganises following Jacobs ECR takeover

Australian-headquartered engineering company WorleyParsons has completed its acquisition of Jacobs' Energy, Chemicals and Resources (ECR) division. The new merged entity, to be known simply as Worley, becomes the largest global provider of project and asset services in the energy, chemicals and resources sectors. Within the sulphur recovery technology area, the two companies' capabilities have been combined into a single global team which will be called Comprimo. Comprimo will be part of the Advisian Front End and Advisory Group. Advisian's Downstream and Market Services as well as Sulphur and Process Technology join Advisian's other global service lines including; Front-End Hydrocarbons, Advisory, Environment, Power &

Transport, Advisian Digital and INTECSEA. Both Advisian and Comprimo are brand names fully owned by Worley.

Worley says that the change means it will be able to offer its clients new process technology and configuration options not previously available, and respond faster to client needs, and in a more local manner, by way of Sulphur Technology Centres of Excellence in five countries including the UK, Netherlands, USA, Canada, and India. In a press release, it added; "together we will bring over 130 years of combined corporate history in the gas treating and sulphur recovery industry as well as new capabilities, experiences, and ideas to usher us forward in the years to come."

UNITED KINGDOM

IMO issues more guidance on sulphur limits

The International Maritime Organisation, based in London, has issued additional guidance over the implementation of the lower 0.5% sulphur limit on bunker fuels that goes into effect from January 1, 2020. The guidance includes sections on the impact of fuel and machinery systems resulting from new fuel blends or fuel types, as well as clarifications on control mechanisms and a standard reporting format for non-availability of fuel oil. Member states also approved the 2019 guidelines for on-board sampling for the verification of the sulphur content of the fuel oil used in ships.

The guidelines seek to lift some of the uncertainty surrounding the implementation of the lower sulphur caps in the year ahead. However, on the topic of exhaust gas cleaning systems, also known as scrubbers, uncertainty remains. The Marine Environment Protection Committee approved a new output on the "evaluation and harmonisation of rules and guidance on the discharge of liquid effluents from exhaust gas cleaning systems into waters, including conditions and areas" in the 2020-21 biennial agenda of the Pollution Prevention and Response sub-committee. There is significant variation on the guidelines surrounding the use of open-loop scrubbers among IMO member states, which the committee seeks to address, albeit in 2021, a year after the lower sulphur cap goes into effect. Some members already ban the use of open loop scrubbers over concerns about the discharge of polluted wash water into the sea. Some 80% of scrubbers already or about to be fitted to ships are open-loop scrubbers, while 16% are hybrid scrubbers enabling ships to operate in both open and closed loop.

UNITED STATES

Koch subsidiaries to offer low sulphur fuel technology

Koch Industries subsidiaries Invista Performance Technologies (IPT) and Koch-Glitsch are to expand their partnership to offer the proprietary *ExoS*™ sulphur removal technology to customers. The technology helps refineries to meet new more stringent sulphur fuel standards. The *ExoS*™ process technology – developed and commercialised by the China University of Petroleum in Beijing and Hebei Refining Technologies uses a proprietary solvent to extract sulphur and aromatics from mid-cut FCC naphtha (C6/C7). The sulphur-rich extract is sent to the FCC hydrotreater for sulphur removal while the olefin rich raffinate with less than 10 ppm sulphur is sent directly to the blending pool. This reduces the hydraulic load on the hydrotreater and avoids the saturation of the high-octane number olefins. Koch says that it allows reduced hydrotreater size, lower operating expenditure, and capital expenditure when installed with a new hydrotreater. There are currently eight units in commercial operation and seven in the design and construction phase.

"Refineries worldwide are facing the challenge of ever decreasing total sulphur limits in the gasoline pool," said Christoph Ender, Koch-Glitsch senior vice president of global sales and business development. "Expanding our partnership with Invista Performance Technologies to offer *ExoS* will provide our customers with a valuable solution that is easier to operate, lower in cost, and more environmentally friendly to stay ahead of the sulphur curve versus hydrotreating alone."

Membranes for sour gas processing

Researchers at the Georgia Institute of Technology in Atlanta, in collaboration with the King Abdullah University of Science and Technology (KAUST) in Saudi Arabia, say that they have developed membranes which can sweeten sour gas. The membranes developed by the team are based on an organic amidoxime polymer with varying chemical modifying groups attached. The membranes' porous structures result in highly selective permeability, especially for the most troublesome H_2S molecules. Tests demonstrate that H_2S and CO_2 can selectively permeate through the membranes from a high-pressure stream of sour gas.

"Over 40% of known natural gas reserves in the United States are sour," said KAUST chemical and biological engineer, Ingo Pinnau. In the Middle East, up to 20 per cent of gas reserves are sour. The problem affects many other gas reserves worldwide. Pinnau says the innovation came together when his own earlier work on developing selectively porous membranes was combined with the expertise and state-of-the-art facilities for handling high pressure and toxic gas streams at Georgia Institute of Technology. The collaborators now hope to improve and extend their membranes' capabilities and move towards commercialisation.

OMAN

Contract awarded for Duqm petrochemical complex

The Duqm Refinery and Petrochemical Industries Co (DRPIC) has contracted John Wood Group PLC to provide front-end engineering design for a proposed onshore petrochemicals complex in the Duqm Special Economic Zone on Oman's southeastern coast. DRPIC is a joint venture between state-owned Oman Oil Co. and the Kuwait Petroleum Corp. Wood's capital projects teams in Oman and the UK, which will begin work under the contract immediately, will complete FEED services on the project by third-quarter 2020, according to the company. DRPIC is planning a 230,000 bbl/d refinery and petrochemical complex at Duqm, with three EPC contracts now given formal notice to proceed. The $5.75 billion refinery is due to be completed in early 2022. Primarily designed to produce and recover naphtha, jet fuel, diesel, and LPG, the Duqm refinery will include units for hydrocracking, hydrotreating, delayed coking, sulphur recovery, hydrogen generation, and Merox treating.

ICELAND

Iceland proposes tougher sulphur fuel regulations

Iceland's Ministry for the Environment and Natural Resources has published amendments to current regulations which, if approved, would see marine fuel sulphur limits in Iceland's territorial waters reduced from 3.5% to 0.1% from 2020. Should the proposed amendments be adopted, the 0.1% sulphur cap would bring Iceland into line with sulphur limits in the Baltic and North Sea emission control areas (ECA).

IRAN

Second phase of Ilam gas plant gets go-ahead

According to Iranian news sources, the second phase of Ilam Gas Refinery in the western province of Ilam will begin construction soon, increasing the plant's output by 50%. The National Iranian Gas Company has tasked the Iranian Gas Engineering and Development Company with the project, according to the Iranian Oil Ministry. The gas processing plant currently has a capacity of 6.8 million cubic meters of sour gas per day as feedstock (240 million scf/d), and this volume will increase to 10 million cubic metres (360 million scf/d) when the second phase comes online. The gas plant produced 60,000 tonnes of sulphur last year, half of which was used by local industries and 30,000 tonnes exported.

RUSSIA

Russia's Kharyaga field starts gas sales

The first associated gas has been sold from the Kharyaga sour gas field and reached the Usinsk gas refinery operated by Lukoil-Komi LLC for further processing, according to lead operator Zarabuzhneft. The gas supply commenced ahead of schedule. The total capacity of sales gas output will eventually reach 18 million Nm3/year. At present the plant is able to run at 44% of capacity, increasing to 74% with the completion of an amine gas treatment unit. It is planned to reach 95% by the end of 2021 after completion of the CPF modernisation Stage VI. Zarubezhneft operates the field under a production sharing agreement with a 40% interest. Its partners are Equinor (30%); Total (20%); and Nenets Oil Co. (10%).

MALAYSIA

Malaysia offers "significant sour gas opportunities"

According to research by natural resources consultancy Wood Mackenzie, Malaysia offers some of the most material and attractive upstream investment opportunities in Southeast Asia, primarily due to the need for additional gas supply. The multiple breakdowns in the Sabah-Sarawak gas pipeline and a delayed final investment decision (FID) on the large Kasawari gas project have resulted in short-term supply crunch to the Bintulu MLNG plant. WoodMac sees this supply shortage persisting though until at least 2025, when major new fields are likely to be brought onstream, including Jerun, Timi, Rosmari, Marjoram and Kasawari.

"This is a golden opportunity for upstream players to swiftly bring gas onstream and jump ahead of the queue: either in the form of increasing existing production, or by developing smaller discoveries to tie into existing infrastructure. But speed is the key," said upstream research director Angus Rodger at the 20th Asia Oil & Gas Conference in Kuala Lumpur.

The most prospective basins for new discoveries and undeveloped gas resources in Malaysia are in offshore Sarawak. In this region, Wood Mackenzie estimates there is already 17 trillion cubic feet (tcf) of discovered and undeveloped gas that is commercially viable. However, as many of the easiest fields have already been commercialised, those that remain will be more difficult and costly to develop. For example, half of the 17 tcf requires investment in technology to process higher levels of carbon dioxide and/or other contaminant, including H_2S.

New refinery to meet bunker fuel demand

Trading firm Vitol has started construction of a small refinery in Malaysia geared to producing marine fuel compliant with the International Maritime Organisation (IMO) 0.5% sulphur cap. Construction has already begun on the 35,000 bbl/d facility, at the Tanjung Bin oil products storage terminal, which is part owned by Vitol, and which is only a few kilometres from the major bunker fuel and shipping hub of Singapore. The facility is due to be operational in 3Q 2020.

TURKEY

Star refinery commissioned

Azerbaijani state oil company SOCAR says that it has completed testing and commissioning of all of the units at its new Star refinery in Turkey. The company says that it will be processing 8 million t/a of crude oil once the refinery reaches capacity towards the end of 2019. Most of the oil is coming from Russia, but the refinery is also looking to Iraq for supplies. The $6.3 billion refinery is sited in the Aliagha district near the Turkish city of Izmir. At capacity, it will produce 1.6 million t/a of naphtha, 1.6 million t/a of aviation fuel, 4.8 million t/a of low-sulphur diesel fuel, 700,000 t/a of petroleum coke, 420,000 t/a of mixed xylene and 160,000 t/a of sulphur. SOCAR has a controlling 51% stake in the neighbouring Petkim petrochemical complex.

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Sulphuric Acid News

ZAMBIA

Copper smelter re-starts but future remains uncertain

Konkola Copper Mines (KCM), owned by Vedanta Resources, re-started production at its Nchanga smelter on June 22nd. The smelter had been idle due to lack of availability of copper concentrate, which is normally supplied across the border from the Democratic Republic of Congo (DRC), but supplies of which had been halted last year by the imposition by Zambia of a 5% import tax on concentrates from the DRC, which KCM said made operating the smelter economically unviable. Vedanta says that it has invested $3 billion in KCM after buying its stake in 2004, but says that it made an operating loss of $95 million in the six months to September 2018. It says that the new tax, coupled with a 1.5% increases in government royalty payments, has taken the cost of copper production to $7,800/t, compared to a current market price of below $6,000/t.

However, in response to the shutdown of the smelter, the government has gone after KCM, trying to revoke its mining license. Vedanta owns 80% of KCM, but the remaining 20% is owned by government controlled ZCCM-IH. Via ZCCM, the government has applied to provisionally liquidate KCM, and according to Reuters says that it has had bids to purchase KCM from China's Nonferrous Metals Mining Corporation (CNMC), commodities trader ETG Group and an unnamed Turkish firm. CNMC were said to have offered $2 billion. The government has appointed a liquidator, but on June 27th a court issued an order halting any move by the liquidator to dispose of KCM's assets or make arrangements with its creditors.

PHOTO: KCM

Tailings leach plant at KCM.

KCM is not the only company in trouble with the Zambian government. Glencore has been criticised for closing two shafts of its Nkana mine at Kitwe, even though this is because the reserves there have become exhausted, and the government has called for the operations to be passed to local contractors to prevent job losses.

Parallels have been drawn with the Zambian government's previous nationalisation of the copper sector in 1969, which led to years of underinvestment and structural decline which saw production collapse from 700,000 t/a to less than 250,000 t/a by 2000. Allowing foreign investment back in has led to production rising rapidly to 860,000 t/a in 2018, and Zambia becoming one of the centres of supply for the world's copper and especially cobalt industries. However, production may be down by 100,000 t/a this year because of the shutdowns at Nchanga and ERG's Chambishi smelter. ■

RUSSIA

Outotec to build copper leaching plant for Baikal

Outotec has signed a contract with Baikal Mining Company for the design and delivery of a €250 million greenfield copper concentrator and hydrometallurgical plant for the Udokan project in the Kalarsky District of Russia's far East. Outotec's scope of works includes basic and detailed engineering of the concentrator and copper hydrometallurgical plant, procurement, delivery of main process equipment as well as installation supervision, training and start-up services.

The new metallurgical complex is expected to operate with an annual capacity of 12 million tonnes of ore, producing 130,000 t/a of copper as high grade sulphide concentrate and cathodes. Outotec's main equipment deliveries are expected to take place in 2020, with plant start-up scheduled for 2022.

"Udokan is the world's third largest known undeveloped copper deposit. We are extremely pleased about being selected as a technology partner in this significant project. Our proven technologies and services enable Baikal Mining Company to develop their operations in a sustainable way and get the best value from their assets," said Markku Teräsvasara, CEO of Outotec.

Baikal has developed a unique flotation and hydrometallurgical ore processing flowsheet including bulk and sulphide flotation, leaching, solvent extraction and electrowinning as a result of long-term research conducted by BMC with major Russian and international engineering companies.

INDIA

Sterlite court case continues

At the end of June and start of July, the Madras High Court heard petitions from the Tamil Nadu government and Sterlite Copper's parent company Vedanta concerning the ongoing closure of the copper smelter at Tuticorin. The Tamil Nadu government via the State Pollution Control Board (TNPCB), is fighting to keep the plant closed on a permanent basis, alleging that it is responsible for pollution of the local area – the permanent closure came after police clashed with protestors outside the plant in 2018 leading to 13 deaths. Vedanta denies the allegations that its plant caused any pollution, arguing that there are 67 industrial plants in the vicinity, including three coal-fired power stations, all of which could be the source of sulphur dioxide emissions. Vedanta admits TNPCB had ordered the removal of copper slag from the local river, but argues this was to prevent it blocking river traffic, not because it was a pollutant. However, some smelter slags are known to leach heavy metals into water courses.

Vedanta says that the closure of the smelter has so far cost the company $200 million. In the 2017-18 financial year, it supply one third of India's 675,000 t/a of copper demand. The plant has the capacity to process 400,000 t/a of copper, producing 1.2 million t/a of sulphuric acid.

Hindustan Copper to expand ore production

State-owned Hindustan Copper Ltd (HCL) says that it has signed a memorandum of understanding with the Indian Ministry of Mines to raise its copper ore production from 4.12 million t/a in the 2018-19 financial year to 5.15 million t/a in fiscal year 2019-2020. It forms part of an ambitious expansion plan to raise its copper output to 20 million t/a by 2025 at a projected cost of $870 million. This will include re-opening the Rakha mine in Jharkhand this year, closed in 2002 and beginning operations at the Chapri-Sidheswar mines in the same state. However, dewatering and other operating measures could take 3-4 years according to HCL. Other projected production will come from the

Malanjkhand project in Madhya Pradesh, where the company is expanding production from the present 2 million t/a to 8 million t/a by developing an underground mine below the existing open cast mine. At the Khetri and Kolihan mines in Rajasthan, production is expected to increase from 1 million t/a to 3.5 million t/a.

CHINA

Merger creates phosphate giant

China's state-owned phosphate producers Wengfu and Kailin merged to become the country's largest phosphate and NPK producer, and the third largest in the world after OCP and Mosaic, with a phosphate fertilizer capacity of more than 10 million t/a, including 6 million t/a of diammonium phosphate (DAP). Both companies are based in Guizhou province in the southwest of China, and prior to the merger were the second and third largest phosphate producers in China, behind Yuntianhua (YTH). The provincial government of Guizhou has expedited the merger, which will give the combined firm phosphate reserves of around 1.5 billion tonnes, accounting for 40% of China's total, according to consultants CRU. China produced 17.0 million tonnes P_2O_5 of phosphate fertilizer in 2018, down 0.9% due to environmental restrictions on production.

China's import restriction driving Asian smelter capacity

China has followed its ban on imports of Category 7 copper scrap on January 1st with a new ban from July 1st on Category 6 material, including stripped wires and cables. The move comes as part of a Chinese crackdown on imports of international waste, formalized as a three-year "Action Plan for 'Winning the Blue Sky War', designed to reduce air pollution by up to 18% by 2020. The move has left east Asia awash in copper scrap which can no longer be exported to China to be re-melted, and has led to the developments of new, often Chinese–owned copper smelting projects elsewhere in the region, including Cambodia, Indonesia, Malaysia and Thailand. Malaysia's imports of copper scrap and waste increased from 19,000 t/a in 2017 to 230,000 t/a in 2018, according to the International Copper Study Group (ICSG).

AUSTRALIA

Ardmore looking to late 2019 start-up

Centrex Metals says that its Ardmore phosphate rock project is due to begin operations in late 2019, proceeding to full scale development next year. Centrex has recently bought a pilot wet processing plant from CDE Meta to produce phosphate concentrate by washing, scrubbing and de-sliming ore to produce 35% P_2O_5 and ultra-low cadmium phosphate rock concentrate to be used in the manufacture of phosphoric acid. The pilot unit has a capacity of 70 t/h, and has been designed to accommodate the expansion of the plant in phase two, which is expected to double the scale of the operation to process 140 t/h, equivalent to 800,000 t/a of wet concentrate at a target level of 3% moisture. During phase one, the pilot plant will provide up to 30,000 t/a of concentrate to a number of Centrex Metals customers.

King River looking at acid leach for metals project

King River Resources Ltd says that it is pleased with progress of a pre-feasibility study as it considers the best commercialisation strategy for the Speewah Specialty Metals Project in the East Kimberley region of Western Australia. As part of the study, test work is ongoing to investigate an agitated tank leach process for the metal concentrate using sulphuric acid. The company says that capital and operational expenditure costings support this as the preferred process route to produce vanadium pentoxide, titanium dioxide and iron oxide products. Test work has successfully produced an iron oxide product assaying 67% iron with low contaminants using an iron reduction method on a sulphuric acid leach solution, left over from agitated vat leach and column leach tests carried out earlier this year, which had already achieved up to 97% vanadium and 62% titanium extraction. King River has also produced an intermediate titanium dioxide product assaying 80% titanium dioxide using the hydrolysis on the remaining sulphuric acid leach solution, after iron reduction and precipitation of iron sulphate. Como Engineers, who performed the scoping level engineering study, concluded that total capex including a sulphur-burning sulphuric acid plant is likely to be around $675 million. Como is seeking indicative pricing on other sulphuric acid plants suitable for the project.

The Speewah deposit has reserves of up to 4.7 billion tonnes at 0.3% vanadium pentoxide, 3.3% titanium dioxide and 14.7% iron.

KENYA

Geothermal power plant considering acid production

Kenyan electricity company KenGen, which operates the Olkaria geothermal power plant in western Kenya's Great Rift Valley, says that it is considering commercial sulphuric acid production from the site as part of a major industrial park development. The company is looking to diversify its revenue streams, and has invited investors to set up export-only textile and apparels plants on a 309-acre industrial zone in Naivasha. The KenGen Green Energy Industrial Park will have four zones and be connected by rail to the port of Mombasa, providing not only access to shipping but also cheap and stable green electricity, and hot brine and geothermal steam.

The geothermal fluids in the Olkaria reservoir are a complex mixture of salts of sulphates and carbonates and also contain dissolved hydrogen sulphide, which can lead to extensive corrosion of buildings from geothermal plumes as the H_2S oxidises to sulphuric acid. ■

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People

Tom Simpson.

The Sulphur Institute (TSI) says that **Tom Simpson**, Director, Sulfur Purchasing at Nutrien Ltd. has assumed responsibilities as the organisation's chairman of the board. **John Bryant** has assumed the role of TSI president and CEO, following the retirement of **Robert McBride**. Both appointments were made following TSI's Annual General Meeting in April.

Simpson said, "It is an honour to be named TSI's Chair. I look forward to working with the Institute and its members to advocate on behalf of the sulphur and sulphuric acid industries. I would like to thank Rob McBride for his five plus years of dedicated service as the president and CEO of The Sulphur Institute. Rob came to us at a critical time and he has put the Institute in a great place for future growth and expansion of services. I would also like to welcome John to the TSI Management Team. He is a veteran in the industry, and I look forward to partnering with him on future endeavours."

Neil Bruce, SNC-Lavalin Group Inc.'s chief executive, is stepping down from the engineering company after a nearly four-year tenure that saw its stock fall by roughly half and its projects overshadowed by a political controversy tied to an ongoing corruption case. **Ian Edwards**, the company's chief operating officer, has been named interim chief executive. SNC-Lavalin said the board of directors has asked Edwards to review "the strategic direction of the company on an expedited basis" and develop a new plan "for sustainable success."

Bruce became CEO of Lavalin in October 2015 and steered the company through its purchase of WS Atkins in 2017, but has also overseen a difficult period for the company relating to fraud and corruption charges stemming from its work in Libya, as well as becoming caught up Canada's ongoing diplomatic row with Saudi Arabia which has halted work on projects there. A legal dispute with Codelco at Chuquicamauta in Chile saw its $260 million contract there terminated in March. The company twice halved its 2018 profit forecast and halted all bidding on future mining projects, and recently announced plans to wind down its operations in 15 countries at the same time that it reported a $17 million loss in its latest quarter.

SNC Lavalin has also announced the appointment of **Nigel W.M. White** as executive vice-president for Project Oversight, from August 1st, 2019. White will lead the newly created Project Oversight function, which will underpin the Company's four operational sectors, reporting to Ian Edwards, and based in the UK. White has 32 years of experience in managing all aspects of civil, building, foundation and electrical and mechanical contracts in Hong Kong, UK and USA. Prior to joining SNC-Lavalin, he was Executive Director at Gammon Construction Limited in Hong Kong where he had overall responsibility for the company's operations together with financial performance responsibilities, business growth strategy and business development.

Corrosion Resistant Alloys has appointed **Matt Pond** as chief financial officer. Headquartered in Houston, Pond will be responsible for spearheading expansion of just-in-time manufacturing capabilities, developing strategic business relationships with global operators and serving as a member of CRA's corporate leadership team. Pond has almost 20 years of executive level industry experience, starting at Energy Alloys and serving as the vice president of business development at CRA. He also partnered and co-founded various oilfield materials companies including Smith Material Solutions, SMS Precision Tech, NewTech MWD Services and Frontier Oil Tools.

Calendar 2019/20

SEPTEMBER

16-20

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

OCTOBER

7

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

7-10

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

NOVEMBER

4-7

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

4-7

CRU Sulphur and Sulphuric Acid 2019 Conference, HOUSTON, Texas, USA
Contact: CRU Events
Chancery House,
53-64 Chancery Lane,
London WC2A 1QS, UK.
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

FEBRUARY 2020

Date T.B.A.

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

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

From deficit to surplus

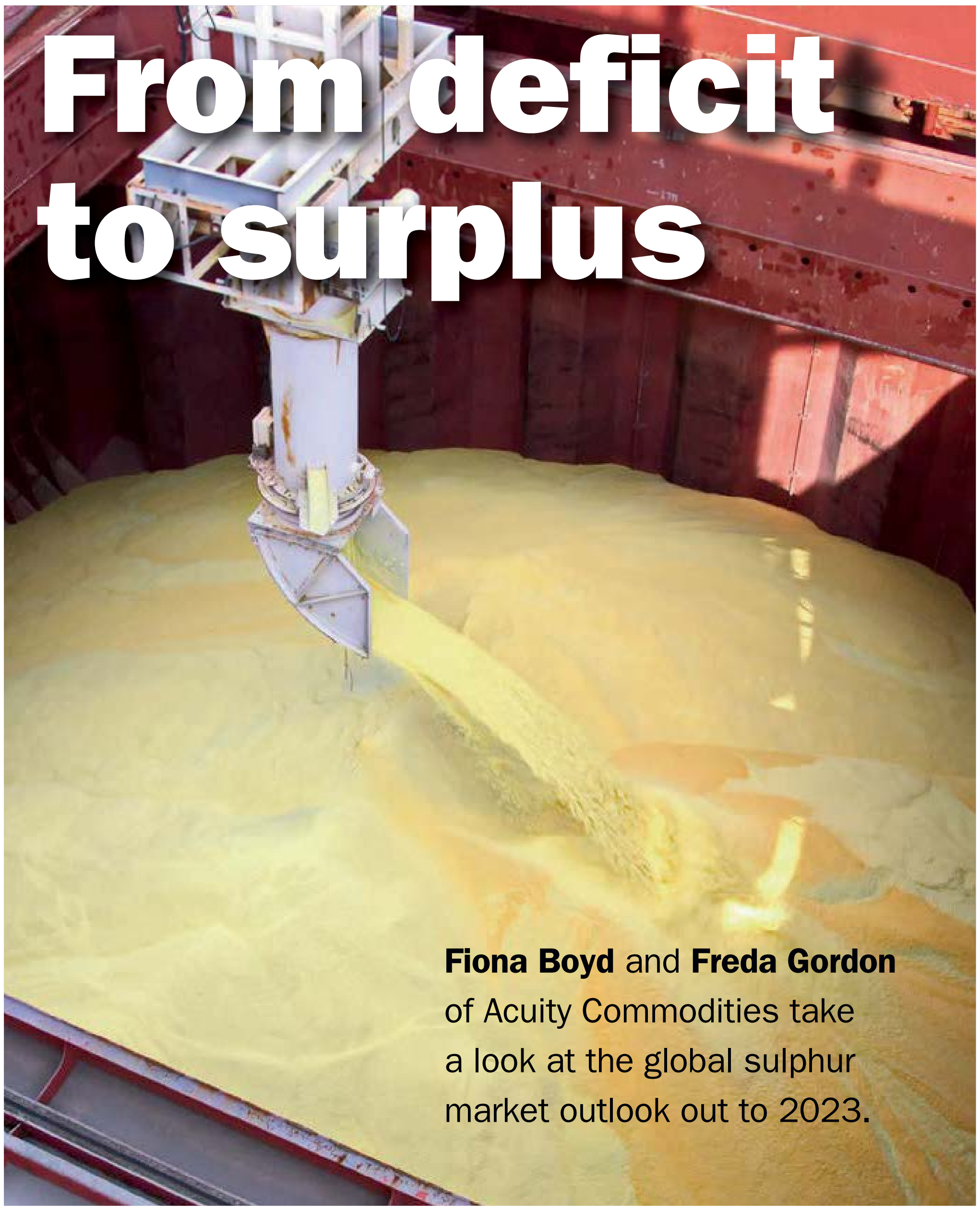
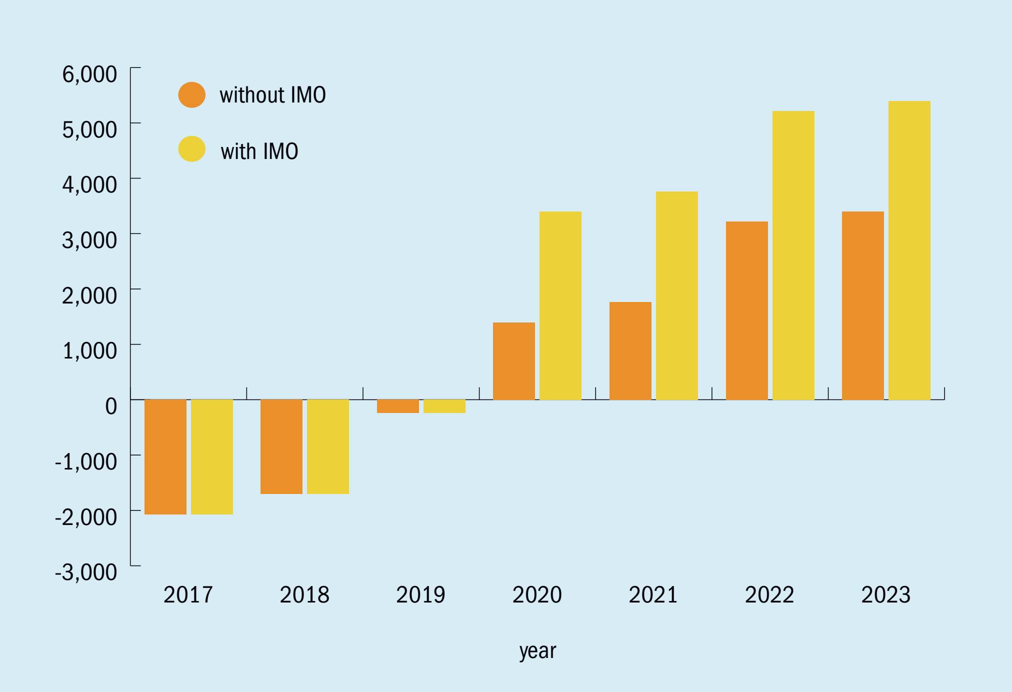


PHOTO: IVAN KUZKIN/SHUTTERSTOCK.COM

Fiona Boyd and **Freda Gordon** of Acuity Commodities take a look at the global sulphur market outlook out to 2023.

Fig. 1: **Global Sulphur Balance ('000 metric tonnes)**



Source: Acuity Commodities

As the world demands lower sulphur dioxide (SO_2) emissions and lower sulphur content in refined products, the supply of sulphur continues to increase. Oil refineries and natural gas processing plants around the globe are increasingly required to capture more sulphur as a by-product.

Over the past couple of years, the new supply of by-product sulphur has moved in tandem with rising demand to keep the two markets relatively balanced. The overall sulphur market in 2017 was in deficit to the tune of 2 million t/a, which is a relatively small deficit for a market with an overall trade volume of around 35 million t/a. For 2019, Acuity is forecasting the sulphur market to be undersupplied by 240,000 t/a, before rising to a surplus of 3.4 million t/a in 2023 (see Figure 1).

Last year and 2017 were both deficit years for the sulphur market, resulting in some volatility in sulphur pricing. The rise of the sulphur import price into China to $200/t c.fr in 4Q17 was unexpected, fuelled by speculative buying in China and a loss of production in the US after the landfall of hurricane Harvey. Going forward, we expect pricing volatility to decline as the market moves into surplus.

Market factors

Although over 90% of global elemental sulphur production is used for the production of sulphur-based sulphuric acid, the demand for these two products is driven by different industries. We tend to see the price of sulphur being heavily influenced by market fundamentals and the pricing of phosphate fertilizers, while sulphuric acid price movement tracks fundamental changes in the markets for base metals, namely copper, nickel and zinc. For example, in 2018 when base metal prices in general picked up, the consumption of sulphuric acid increased, partly supporting acid pricing. On the sulphur side, so far in 2019, application of phosphate fertilizers has been delayed in many key consuming regions, which has resulted in slower than expected sulphur consumption, too.

In addition to fundamentals in the phosphate fertilizer market being mostly bearish at the time of writing, mainly due to oversupply, geopolitical issues are also influencing the market. The ongoing trade war between the US and China is having a negative impact on sentiment across many commodities. This has impacted crop

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prices, which in turn may influence the use of fertilizers and therefore, prices for raw material sulphur and sulphuric acid.

The impact of the trade war on actual trading of sulphur and sulphuric acid has been minimal, however. In fact, since the two countries added sulphur and sulphuric acid to their tariff lists towards the end of 3Q 2018, trade flows have been little affected because the volume traded between China and the US is relatively small. Nevertheless, Chinese importers of US sulphur will feel a bigger impact than everyone else in the industry. This is because China imported 272,000 tonnes of sulphur from the US last year. We note that this total was down 9% on 2017's 299,000 tonnes, which can be attributed to the imposition of higher import taxes on these two products beginning in late 3Q 2018. The total of US supply to China is negligible when the latter's 2018 import total of 10.8 million t/a is considered, however.

We have also seen US sanctions on Iran and Venezuela impact upon the sulphur market. In the case of Venezuela, reduced heavy crude availability for US refiners due to now limited imports from Venezuela is impacting on crude slate runs. This is because the price of heavy crude is now less economical versus lighter grades due to the overall lower supply, thereby limiting incentives for refining of heavier crude. As a result, some refiners are producing less sulphur than they have done historically.

While the impact of these geopolitical issues is hard to call, they are certainly a focus for many industry stakeholders. Specifically for sulphur we have seen speculative traders adopting a more cautious approach and becoming reluctant to take positions, therefore reducing the liquidity of sulphur trade between 4Q18 and 1Q19. Bearing in mind the slightly clouded market outlook because of this geopolitical uncertainty, we now turn to known supply and demand changes in the market between 2019 and 2023, including key trends that will shape the market.

Key influencers

There are some key supply and demand factors which are influencing both the sulphur supply and demand sides of the market. Firstly, we expect to see more supply as a result of the International Maritime Organisation (IMO) 2020 regulation. The regulations stipulate that, as of January 1, 2020, the sulphur content in marine fuel must be at, or below, 0.5%, compared with the current 3.5% limit. This is causing havoc on the shipping side as ship owners prepare for the transition. It is also presenting challenges for refiners as they work to have compliant fuels available in time and in sufficient quantities. Several refiners have not been proactive in making modifications. This is largely due to the uncertainty surrounding IMO 2020 and because investments made based solely on government policy are seen as risky in case that policy is delayed or cancelled. Also, the time needed to make refinery upgrades ahead of the deadline was not adequate.

On the demand side, we see the electric vehicle (EV) evolution as bullish because of the high use of metals for materials such as batteries, cars, more charging stations and grids. This supports expectations of increased demand for sulphuric acid for metals leaching. The EV evolution is neutral from a supply perspective because fuel demand for cars is not as significant as it is for other sources.

In terms of overall sulphur consumption, we also expect growing fertilizer demand and therefore the need to support phosphate fertilizer production as a bullish factor. In addition, sulphur deficiency in soils could boost demand for sulphur-enhanced fertilizer products.

From a neutral perspective, however, we see that demand will face a regional shift due to changes in the phosphate production landscape. China is one of the countries that will lose competitiveness in the phosphate production arena as additional low-cost production capacity is being added in Morocco and Saudi Arabia, for example.

Supply – delays still common

We expect global supply to increase in the coming years. This is due to the development of refinery and natural gas processing capacity globally. An example of this is in India, where new fuel standards are required by April 2020. The transition to Bharat Stage VI standards will see sulphur content in fuel reduced from 50 parts per million (ppm) to 10ppm in the country. This is driving numerous refinery expansions and upgrades at present.

Some of this growing production will be offset by declining production from natural gas, however, which is more prevalent in North America and Europe – notably Germany where the production of natural gas has declined over the years and now appear to be flattening out.

However, sulphur supply from some regions will not move to the merchant market if the price does not support it – this applies to swing crushed lump sulphur supply from Saudi Arabia and granular sulphur supply from Turkmenistan, for example. There is also some building of inventory in Canada if pricing is not favourable, but this has declined in recent years. Canada is home to the largest accumulation of sulphur inventory in the world at around 10 million tonnes, so the idea in the past few years has been to keep product moving as to not grow the inventory problem.

The world's largest sulphur producing regions by 2023 will be West Asia (the Middle East), North America and East Asia. West Asia's supply growth will be the most significant because of many large-scale refinery developments. These include the Jazan project in Saudi Arabia and the Al Zour refinery in Kuwait, which are both expected to be operational before the end of 2019, although reports of delays at Al Zour have been recently heard. Numerous sour gas projects in West Asia will also contribute to the supply increase.

As for North America, it will be the second largest sulphur producing region in the world by 2023, but its production from natural gas will be declining, particularly in Canada. As an indication, production declined by around 600,000 tonnes just between 2015 and 2017. This has offset gains in the refining and oil sands upgrading sector in both Canada and the US.

In East Asia, we anticipate increasing refining and natural gas processing capacity, for example new refining capacity in China, Malaysia and plans for a large-scale refinery in Indonesia.

Demand – East Asia and Africa

We expect growing populations and consequent increases in fertilizer demand to increase sulphur consumption. However, we do expect some production shifts. In particular, Saudi Arabia and Morocco have a lower cost of phosphate fertilizer production compared with China and the US. This is expected to result in industry rationalisation in the relatively higher-cost regions. For example, we saw Mosaic idle its Plant

City, Florida phosphate production in late 2017, citing more favourable production economics in Saudi Arabia where it has a stake in producing assets that came on stream in 2017. The Plant City idling reduced Mosaic's overall sulphur consumption accordingly. In its 1Q19 financial results, Mosaic said it will make a decision by July 2019 on if Plant City will resume operations and we fully expect that it will not restart the facility.

In terms of consuming regions, the top three by 2023 will be East Asia, Africa and North America. In East Asia, the growth will be driven by China and Indonesia, but environmental rules and phosphate fertilizer rationalisation are concerns, particularly in China. Stringent environmental policies will continue to affect China's fertilizer output and therefore its sulphur consumption and import. For example, the "Three Phosphorus Plan" will affect all fertilizer plants located in Hubei, Guizhou and Yunnan – a key phosphate production area (see box).

It is hard to quantify the amount of sulphur demand that will be affected. From Acuity's point of view, however, the biggest disruption to sulphur demand as a result of tightening environmental rules in China is already behind us. When these policies were first imposed several years ago, the plants that failed to qualify to run should have already relocated, reconfigured or shut. Nevertheless, we continue to watch the development of the "Three Phosphorous Plan" closely because it has the potential to continue to squeeze China's sulphur consumption, as it is specifically targeting the phosphorus industry.

Africa will be the world's second largest sulphur consuming region by 2023, of which Morocco will be leading the growth. Morocco's OCP continues to expand its downstream production and own sulphuric acid production capacity. For example, in 2018, it started the JPH4 production hub which comes with a sulphuric acid unit with nameplate capacity of 1.5 million t/a, which entered its commissioning phase at the beginning of April 2019. Between 2020 and 2023, the JPH5 and JPH6 projects will come, with two more sulphuric acid plants of similar capacity. It is therefore reasonable to assume that OCP will be further increasing its sulphur imports, while potentially lowering its sulphuric acid import requirements in the medium to long term (see Figure 2).

China's stringent environmental rules 2018

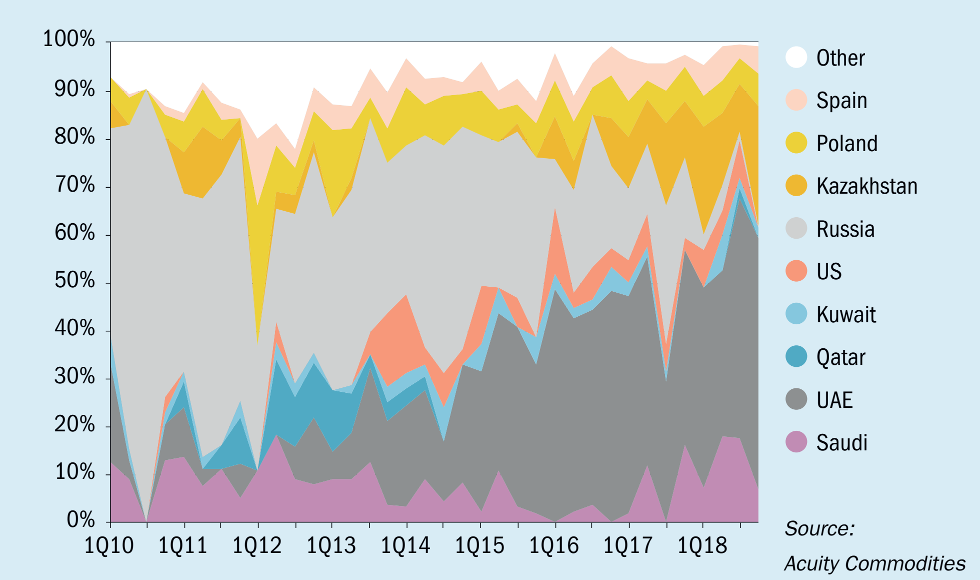
Mid 2019
China stepped up its environmental protection efforts, led by the Environmental Protection Bureau. Regular inspections were coupled with legal and financial punishments, and by exposing those who failed.

Mid 2019
China focuses on the protection of the Yangtze river. The "Three Phosphorus Plan" (三磷) will target phosphorus related operations in Hubei, Guizhou and Yunnan. Inspections will take place before mid 2019.

End 2019
Operations who failed will have been notified the time they have to rectify their issues.

End 2019
The key round of rectification will have concluded by now and all operations will have to adhere to new and higher standards set out by local governments.

Fig. 2: **Morocco sulphur imports: rising S requirements & supply diversification**



Source: Acuity Commodities

From deficit to surplus

More supply than demand will push the market into a surplus in the years to come. But the question continues to relate to timing of these new supply and demand projects – particularly on the supply side. As market surplus grows, price volatility is expected to ease.

For 2018, we estimated that the market was in a deficit state, with demand outstripping supply by 1.7 million t/a. For 2019, our forecast is a smaller deficit of 240,000 t/a. From 2020 onwards, the market will enter a surplus again, reaching an oversupply of 3.4 million t/a by 2023. If we consider the impact of IMO 2020, the oversupply by 2023 could reach 5.4 million t/a.

With West Asia being the top producing region, pricing strategy by the producers there will have an influence on global pricing. More Middle East production is now sold on a contract basis, rather than as spot. Quarterly pricing negotiations are still used for some contracts between producers and offtakers, but more and more contracts are now linked to the monthly lifting prices as well as indexes.

We also note that more and more Middle East cargoes are sold to end-user markets on a c.fr basis by the producers – this can reduce traders' competitiveness in end-user markets, particularly for those who have an f.o.b. contract with the producers.

Acuity Commodities provides insight into the sulphur and sulphuric acid markets through price assessments, data and supporting analysis. Offerings include weekly reports on the global sulphur and sulphuric acid markets and a bi-weekly report focusing on North America as well as bespoke consulting work. Please visit www.acuitycommodities.com for detailed information.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Southern Africa's sulphur and sulphuric acid industries

The Kansanshi copper mine, Zambia.

PHOTO: KCM

Sub-Saharan Africa is a net importer of sulphur, mainly to feed phosphate and metals production. The sulphuric acid picture is complicated by new sulphur burning acid plants and taxation disputes with copper companies in Zambia and the Democratic Republic of Congo, however.

Sub-Saharan Africa's oil and mineral wealth has attracted considerable inward investment by overseas companies. While the recent stall in the commodities market has put back many plans for new investments, especially in the central copper belt of Zambia and the Democratic Republic of Congo (DRC), environmental improvements to smelters are generating considerable volumes of new acid which are substituting for sulphur imports in some areas.

Regional sulphur sources

Sub-Saharan sources of sulphur are extremely limited. The only significant producer is South Africa, at about 280,000 t/a. A good proportion of this comes from sulphur recovered from coal and gas to liquids production at Sasol, but the rest comes from refining. The refining sector is relatively underdeveloped in southern Africa. As Table 1 shows, there are 21 refineries, but these combined have a total capacity of only 1.54 million bbl/d, and most of these are small and relatively simple refineries with low

Table 1: **Refineries in sub-Saharan Africa**

Country	Location	Operator	Capacity ('000 bbl/d)
Angola	Luanda	Sonangol	65
Cameroon	Cape Limboh Limbe	Societe Nationale	70
Chad	Ndajamena	CNPC	20
Congo	Pointe Noire	Coraf	21
Gabon	Port Gentil	St. Gabonaise	24
Ghana	Tema	Tema Oil	45
Ivory Coast	Abidjan	Societe Ivoirienne	84
Liberia	Monrovia	Liberia Petroleum	15
Niger	Zinder, Ganaram	CNPC	20
Nigeria	Kaduna	NNPC	110
	Port Harcourt	NNPC	210
	Warri	NNPC	125
Senegal	M'Bao (Dakar)	St Africaine	25
Sierra Leone	Freetown	SLPRC	5
South Africa	Cape Town	Chevron	110
	Durban	Engen (Petronas)	150
	Durban	Shell/BP	180
	Sasolburg	NPRSA (Sasol/Total)	105
Sudan	Khartoum	CNPC	100
	Port Sudan	Sudan Government	47
Zambia	Bwana Nkubwa Area	Zambia Government	12

Source: McKinsey

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

upgrading capacity built many years ago, and suffering from low refining margins, small local markets, high operating costs and poor yields, and often have low operating rates. Only South Africa, with 545,000 bbl/d and Nigeria, with 445,000 bbl/d, have any significant capacity, and represent 65% of the region's refining capacity between them. Some 390,000 bbl/d is represented by just two refineries – Port Harcourt in Nigeria and Sapref in Durban, South Africa.

As a result, sub-Saharan Africa exports oil but imports refined products from the US, Europe, the Middle East or the Far East. West and East Africa particularly pull in growing volumes of gasoil and gasoline last year. Furthermore, new large scale refineries in China, India and the Middle East that have been built over the past few years may start to make even existing capacity unprofitable.

The region is also a large next exporter of oil. In 2018, sub-Saharan Africa produced 4.95 million bbl/d of oil, according to BP's Statistical Review of World Energy, mainly from Nigeria and Angola, but consumed only about 2 million bbl/d, of which refinery throughputs were only about 900,000 bbl/d; an on-stream factor of only 60%. Imports of refined products averaged 1.9 million bb/d.

Coupled this with the fact that Nigerian crude is relatively sweet and local fuel standards relatively forgiving of sulphur content, and there is a dearth of sulphur recovery tonnage in the region, meaning that it has to import most of its requirements from overseas.

New refining capacity

Demand for refined products in the region is forecast to continue to increase as population and car ownership increases. GDP growth currently stands at 3.2% per year for the region as a whole and this is forecast to increase to 3.7% after 2020. In some countries, like Ethiopia, it is more than 7.5%. Coupled with rising fuel standards, with much of the region pledged to move to a 'Euro-IV' (50 ppm) sulphur limit for fuels, there is significant scope for new refining capacity to be built in the region and additional volumes of sulphur to be recovered.

Financing, as well as lack of infrastructure and legal, corruption and governance issues have always proved to be the stumbling block for new capacity developments

Fig. 1: **Sub-Saharan Africa's sulphur production and consumption**

in the past. However, progress is now being made on some major as well as minor projects. The largest and most advanced of these is the $10 billion 650,000 bbl/d Dangote refinery outside Lagos in Nigeria, which is expected to be operational in 2022.

Other new refinery proposals include a 60,000 bbl/d Ugandan project with involvement from Baker Hughes and Saipem, which is currently at the Front End Engineering and Design stage, with a final investment decision expected by the end of 2019 for completion in 2023. Angola has also set its sights on building a 200,000 b/d refinery in Lobito by 2025 along with a smaller plant in Cabinda. Finally, a much smaller 7,000 bbl/d modular refinery is due to come on-stream at Bentiu in South Sudan before the end of 2019, with plans to expand it to 25,000 bbl/d. There have also been discussions about new refining capacity in Sudan, Kenya and Ghana, and Saudi Aramco has reportedly been in discussions with the South African government about building a new refinery in South Africa.

Overhauls of existing refineries are expected to add 5,000 bbl/d of capacity at Dakar in Senegal. The Nigerian National Petroleum Company (NNPC) is overhauling the Port Harcourt refinery complex, and there are upgrades planned at SIR in the Ivory Coast.

Overall, sub-Saharan Africa could see up to 1 million bbl/d of new refining projects come online in the next five years, most of which will be accounted for by the new Dangote refinery.

The mining and metals industries

While sulphur supplies may be fairly limited, there is a sizeable sulphuric acid industry in the region, mostly for metals processing, and sulphur demand has been increasing steadily as a result. Southern Africa contains over 65% of the world's cobalt production – most of that in the DRC, as well as 68% of its platinum, 10% of its copper and 35% of its manganese. China's rapid growth has led to an equally rapid rise in demand for raw materials of all kinds, including base metals, and China's need for copper has generated a great deal of investment in Africa's 'copper belt', stretching across the south of the Democratic Republic of Congo (DRC) and into northern Zambia. More recently, the DRC has also become the main supplied for the increasingly important cobalt industry. Cobalt is used in batteries and the spread of electric vehicle use worldwide has led to increased demand for the metal. The DRC has some of the lowest cost cobalt reserves in the world, and has quickly come to represent nearly 75% of the world's cobalt supply. Other acid consuming industries include uranium and zinc mining as well as phosphates. Sulphur and sulphuric acid production and use is however dominated by just four countries; Zambia, the DRC, South Africa and Namibia.

Copper and cobalt – Zambia and DRC

Zambia was traditionally the largest copper producer in the region, and it expanded production rapidly, rising from 400,000 t/a in 2004 to double that in 2011, much of it based on copper smelting. There however production plateaued and it was rapidly caught up by new, cheaper capacity in the DRC, where a number of solvent extraction/electrowinning (SX/EW) copper leaching operations started up. Copper ores in the DRC average more than 3% copper content, compared to 0.6-0.8% in most other places, and once the conflict in the country, which had run from 1994-2003 and which many called Africa's 'First World War' had ended and the country began to return to some form of stability, it became an increasingly attractive option for investors. By 2013 the DRC was producing more copper than Zambia, although its output also plateaued at this point, as overproduction in the copper industry hit prices and demand.

However, this rough parity between the two countries allowed them to operate symbiotically – the acid surplus from Zambian smelters was exported to the DRC for use in leaching operations and copper concentrates flowed in the opposite direction to be smelted. However, the governments of both countries have recently moved to start recovering more of the value of the copper produced and processed there, and this has upset the balance between the two. Both countries have increased the royalties tax taken on copper production, and Zambia has also added a 5% import tax on copper concentrates from the DRC. This has led to Zambian smelter operators such as Konkola Copper Mines declaring that their operations were now unprofitable, and shutting down. This in turn has interrupted acid supply to the DRC for leaching operations. Zambian copper production was 860,000 tonnes in 2018, but this is expected to fall by 100,000 t/a this year as a result. The DRC actually suspended shipments of copper concentrate to Zambia earlier this year, but relented in March.

Because if its remoteness from major ports, the copper belt of the DRC has some of the highest sulphuric acid costs in the world, at around $520/t, according to Steve Sackett of TradeCorp Africa, speaking recently at the Sulphur Institute's meeting in Prague. This is, in theory, a considerable incentive to build sulphur-burning acid capacity, although that means getting sulphur into the DRC, and the poor roads can mean that sulphur prices can reach $450/t. Still, new acid capacity is coming. Glencore-owned Katanga Mining says that the new 630,000 t/a acid plant at the Kamoto Copper Company will be commissioned at the end of 2019. This year also saw three 250 t/d modular sulphuric acid plants installed at Shalina Resources at Mutoshi.

One wrinkle is that cobalt extraction requires sulphur dioxide, therefore not all sulphur will be converted to sulphuric acid – the Kamoto acid plant has an additional 200 t/d of SO_2 production on top of the 1,900 t/d of acid output. But all told this means a leap in the DRC's acid capacity of 875,000 t/a by the start of 2020. Additional acid will come from China Nonferrous Mining Corp's (CNMC) Lualaba copper smelter in 2020, which will produce 120,000 t/a of blister copper from local copper concentrates. By 2024, the country's acid capacity could rise to 5 million t/a from about 2.5 million t/a at present, turning it from a net importer to a net exporter.

Meanwhile, Zambia has no additional acid capacity on the horizon, but in the absence of demand from the DRC could find itself with a surplus of more than 1 million t/a and nothing to do with it. That, of course, assumes that the smelters continue to operate. When Konkola Copper Mines shut down its Nchanga smelter earlier this year – which produces 1 million t/a of acid – the government declared KCM to be in violation of its mining license and has tried to force owner Vedanta out of ownership. Eurasian Research Group (ERG) also idled its Chambishi smelter in February 2019 over copper concentrate costs, although it resumed operations in June. Chambishi generates 360,000 t/a of acid, which is used for the company's own SX/EW leaching operations.

Uranium – Namibia

Southern Africa's uranium mining is concentrated in Namibia. There are a couple of smaller mines in Niger, and a few years ago there was also some production in Malawi, but in the latter country Paladin Energy's Kayelekera mine was put on care and maintenance in 2014 and Paladin went into administration in 2017.

Namibia's oldest mine was Rio Tinto's Roessing facility, the longest-running open pit uranium mine in the world, but output has been hit by falling ore grades and Rio Tinto is in the process of selling its 69% stake in Roessing to China National Uranium Corporation (CNBC). Roessing uses acid from the Tsumeb metal smelter to dissolve uranium ores, occasionally buying import tonnages via Walvis Bay. At peak production consumption is up to 260,000 t/a of sulphuric acid, although it is typically lower.

Paladin Energy operated the Langer Heinrich mine 50km from Roessing, which produced 1,300 tonnes U_3O_8 in 2017, but this was idled and moved to care and maintenance in 2018 due to low uranium prices. Paladin is now completing a feasibility study on reopening the mine, possibly in 2021.

Swakop Uranium operates the Husab mine. The company is majority (54%) owned by China's CGN-Uranium Resources Co. production began in 2016 and is ramping up to 5,500 tonnes U_3O_8/year by 2020, one of the largest uranium mines in the world, although the site has been dogged by poor relationships with mining unions over safety concerns. A 1,500 t/d sulphuric acid plant forms part of the facility.

Namibia's other sulphuric acid plants are operated by Vedanta Zinc, which runs the Skorpion Zinc mine and NamZinc processing facility, and Dundee Precious Metals, which runs the Tsumeb copper smelter. NamZinc is a unique zinc SX/EW facility with its own dedicated sulphur-burning acid plant with a capacity of 1,150 t/d. Meanwhile the Tsumeb smelter, which started up in 1963, commissioned a 400,000 t/a sulphuric acid plant in 2015 to deal with SO_2 emissions from the smelter, under the auspices of Dundee Precious Metals, who bought the site in 2010 and increased production by 60%. Copper production in 2018 was 49,000 tonnes, and acid output was 240,000 tonnes.

Namibia is relatively self-contained in acid terms. It rarely produces its total capacity of 1.27 million t/a, and what is produced is used domestically for uranium leaching.

Phosphates – South Africa

Sulphur acid consumption in South Africa is dominated by phosphate fertilizer production. South Africa produces finished phosphates and DAP and phosphoric acid producer Foskor buys in acid from local smelters as well as operating 2.2 million t/a of sulphur burning acid capacity in three large trains at Richards Bay. As well as the sulphur burning plants, there are several smelters in South Africa, including the Palabora copper smelter and Zincor zinc smelter, as well as Impala and Anglo American Platinum's precious metal smelters. Smelter output has fallen over the past decade, although tightening SO_2 emissions regulations have led to Anglo-American installing a new wet gas sulphuric acid (WSA) plant at their Polokwane smelter, due to add another 50,000 t/a of acid capacity. South Africa used to sell excess acid to the DRC, but with acid capacity increasing there, there are questions as to where excess South African acid will go to.

Other phosphate producers include Senegal, where sulphur is imported to feed sulphuric acid production for phosphate treatment. Industries Chimique du Senegal (ICS), owned by Indorama, operates two large sulphur burning acid plants with a combined capacity of 1.8 million t/a of sulphuric acid. Production dropped to less than 50% when phosphate demand was crimped by the economic recession, but has bounced back again to about 70% in recent years.

Table 2: **Southern African sulphur demand and sulphuric acid capacity, million t/a**

Year	2004	2014	2024
Sulphur demand	1.05	1.68	2.53
Acid capacity:			
DRC	0.19	1.88	4.89
Namibia	0.35	0.35	0.96
South Africa	3.27	2.71	3.15
Zambia	0.50	2.55	3.19
Total	**4.30**	**7.48**	**12.18**

Source: TradeCorp

Infrastructure issues

As described by TradeCorp's Steve Sackett, infrastructure remains the key problem for getting sulphur and sulphuric acid to Africa's copper belt. The major regional ports are at Dar es Salaam in Tanzania, Beira in Mozambique, Richard's Bay near Durban in South Africa, Walvis Bay in Namibia, and Lobito in Angola. However, as Figure 1 shows, Africa is a huge continent, and the closest of these is 1,600 km from the copper belt, while the furthest (Richard's Bay) is 3,000 km. Added to this are primitive roads which can be washed away by storms – there was considerable disruption caused by Cyclone Idai, for example, which made landfall in Mozambique on March 15th this year. Then there are border crossings, sometimes two or three, often attended by long queues and bureaucracy. An average border queue might stretch for 10-15 km and move only at 2 km per day. Drivers strikes and other disruptions can occasionally make this far longer. All of these add delays and costs to moving acid and sulphur into the region, and mean that even switching from importing acid to importing sulphur to burn to make acid locally may not ease costs or difficulties.

Sulphur balance

The region's major sulphur consumers are South Africa, Senegal and Madagascar, and all are major importers; domestic South African sulphur production is not enough to satisfy local demand. New refinery projects may add some sulphur production in the longer term in Nigeria and elsewhere. However, new sulphur burning acid plants are increasing demand for sulphur in the DRC, at the same time that they are reducing demand for sulphuric acid.

This presents smelter operators with a problem; there are new additions to smelter acid capacity for environmental reasons in several countries, as well as new sulphur burning plants. Table 2 shows the extent to which acid capacity is increasing in southern Africa. However, while previously the DRC was able to act as a 'sink' to take excess smelter acid from Zambia and South Africa, this may not be the case for much longer, presenting an issue for smelter operators who are located far from a port from which they might export. ■

References

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TSI Sulphur World Symposium 2019

The Sulphur Institute's Sulphur World Symposium was held this year in Prague in April.

This year's TSI Sulphur World Symposium saw the retirement of TSI president and CEO Rob McBride, and the accession of John Bryant in those positions, with Tom Simpson of Nutrien taking over as chairman of the TSI board (see page 14).

Central Asian Summit

A new innovation for this Symposium was the addition of an afternoon prior to the conference which focused on the Caspian Sea region, and its sour gas and sulphur production. *Sulphur* editor Richard Hands ran through the various sour oil and gas projects in the region, before Meena Chauhan of Argus looked at the region's sulphur production. She noted that Russia and Kazakhstan are the dominant producers and exporters, their combined exports of 5.9 million t/a in 2018 represented 18% of all traded sulphur, especially now Kashagan is ramping up. However, other producers are logistically constrained and stocks are building. Demand comes from Kazakhstan's uranium industry, but insufficient to meet production.

Global outlooks

Economist Gabriel Stein opened with the world economic outlook. Growth in broad money supply nd share prices have been negative in all major economies in 2018 as compared to 2017, and this, he said, pointed to below average growth in 2019. Central banks are still normalising rates, there are worries of the length of the current period of expansion, and other factors such as Brexit, the US-China trade dispute, the potential for war in the Gulf and the growth of populist governments which are all worrying markets. Recession seems to have been avoided and confidence is returning, but major risk factors still remain.

The global energy outlook, presented by Francis Osborne of Argus, looked at how quickly decarbonisation is becoming mainstream government policy, and whether we might see an end to production and sale of internal combustion engine vehicles in 2030 in Germany, out to 2040 in the UK, France and China. By 2035, electric cars would represent 25% of all new vehicle sales. While this argues for more demand growth for oil in the medium term, perhaps an extra 12% increased by 20205, by 2030-2035 we will be reaching peak oil demand. Meanwhile, the new IMO regulations on fuels are making life difficult for refiners, as it is difficult to desulphurise residues, and this could place a real premium on lower sulphur crudes (0.3-0.7% S), with more US crude exports and a lower call on OPEC production. OPEC is losing its relevance as the breakeven cost of new non-OPEC production is now $30-50/bbl. On the gas side, demand is growing steadily, rising 20-30% by 2030. Gas and wind are displacing coal and nuclear in power generation, and renewables will represent 30-50% of all new power capacity built out to 2040.

Shipping and IMO

The global shipping market is still oversupplied, said Brian Malone of Mid-Ship Group. However, a 35% increase in scrapping is helping to alleviate structural overcapacity, especially in Handymax and Panamax categories, but Capesize markets are still at a historic low point. Seaborne trade continues to grow, by 112 million t/a in 2019 and 120 million t/a 2020. Undoubtedly one of the greatest changes for the sulphur industry over the next year is going to be the January 1st 2020 deadline for switching to lower sulphur bunker fuels. In part this is helping to influence more early scrapping decisions, and a fuel price shock is expected in early 2020.

On the same subject, Adrian Tolson of 2020 Marine Energy said that late decisions on compliance have led to uncertainty in the industry, with many ships only installing scrubbers this year, and only 3,000 out of an estimated 60,000 affected vessels have installed them, albeit the largest ones, which consume most fuel. For large ships the payback period can be less than a year, but for smaller ships it is much more of a nuanced decision. He foresaw an initial demand spike in marine gasoil (MGO), with a longer transition from MGO to very low sulphur fuel oil (VLSFO) as experience and supplier reliability was established. Within two years, VLSFO would dominate as the choice for compliance. A 3 million bbl/d overnight drop in HSFO demand could lower its price from $450/t to $300/t, while VLSFO would settle at a 10% discount to diesel. The outlook seemed bright for refineries with spare coker capacity (mainly in the US), but others would need to switch to sweeter crude or even close. And longer term, might we see a drop to 0.1% sulphur by 2030?

Sulphur markets

Freda Gordon and Fiona Boyd of Acuity Consulting gave their appreciation of the sulphur and sulphuric acid markets. Their discussion of the sulphur market can be found on pages 16-18 of this issue. On the sulphuric acid side, supply growth centres on east Asia, with more smelter acid, as well as sulphur burning plants in Morocco, Saudi Arabia and the Congo. Demand will also come from Morocco, as well as phosphate production in west and east Asia. China is likely to become an increasing acid exporter over the next few years.

Steve Sackett of TradeCorp focused on Southern Africa and its acid-consuming mining industries – there is a fuller discussion of that topic in our article on pages 20-23.

Sulphur forming projects 2019

Sulphur's annual listing of new or recently completed sulphur forming projects worldwide covers both new sour gas and refinery sulphur forming projects as well as upgrades at existing units.

System manufacturer/ supplier	Operating company	Operating site	Units	Product type	Scheduled throughput	New project/ expansion	Scheduled
BAHRAIN							
Enersul	Bapco	Sitra	3	granules	1,500 t/d	new	2020
BELGIUM							
IPCO	Duval	Antwerp, Belgium	n.a.	pastille	n.a.	new	2020
CANADA							
Matrix PDM	Heartland Sulphur	Scotford	n.a.	prill	2,000 t/d	new	2018
CHINA							
Enersul	PetroChina	Anyue	2	granule	700 t/d	new	2019
INDIA							
Enersul	Reliance Industries	Gujarat	8	granule	2,800 t/d	expansion	2019
Enersul	HPCL	n.a.	2	granule	1,000 t/d	new	2020
IRAQ							
Enersul	GazpromNeft	Badra	1	granule	350 t/d	new	2018
IRAN							
Zafaran	Bushehr Petchem Co	Assaluyeh	2	granule	800 t/d	new	2019
ITALY							
IPCO	Econova	n.a.	3	pastille	580 t/d	expansion	2020
KAZAKHSTAN							
Enersul	Caspian General Contr.	n.a.	3	granule	1,500 t/d	new	2020
KUWAIT							
Enersul	KNPC	Mina al Amina	1	granule	1,200 t/d	expansion	2019
Enersul	KNPC	New Refinery Project	4	granule	800 t/d	new	2019
MALAYSIA							
Enersul	Petronas RAPID	Pengerang, Johor	5	granule	2,000 t/d	new	2019
NEW ZEALAND							
IPCO	Refining New Zealand	Ruakaka	2	pastille	200 t/d	new	2019
OMAN							
IPCO	Duqm Refinery	Duqm, Oman	3	granule	900 t/d	new	2021
QATAR							
Enersul	Qatargas	Ras Laffan	2	granule	2,400 t/d	expansion	2019
RUSSIA							
Enersul	Syzran Refinery	Samara	1	granule	350 t/d	expansion	2019
Enersul	Total	Kharyaga	1	granule	350 t/d	new	2019
SPAIN							
Enersul	Petroleos del Norte	Bilbao	1	granule	350 t/d	expansion	2019
TURKEY							
Enersul	Aegean Refinery	Aliaga	3	granule	1,050 t/d	new	2019
US VIRGIN ISLANDS							
Matrix PDM	Limetree Bay Refinery	St Croix	n.a.	n.a.	n.a.	re-start	2019
VENEZUELA							
IPCO	PDVSA	n.a.	2	pastille	264 t/d	new	2019
VIETNAM							
Enersul	Nghi Son Refinery	Nghi Son	3	granule	1,380 t/d	new	2018


The Shah sour gas plant, Abu Dhabi.

SOGAT 2019

Highlights of the Sour Oil and Gas Advanced Technology (SOGAT) conference, held in Abu Dhabi from April 28th to May 2nd 2019.

Though attendance is down from its heyday, the SOGAT conference remains a technical showcase for those operating in the sour gas industry, which Abu Dhabi is now at the forefront of. Giving the opening address, Frank Gutzebrock of Adnoc Gas Processing said that this was a boom time for the gas industry, with the US now becoming an LNG exporter and a shift of demand growth from power production, as renewables take an increasing share of new power generation capacity, to industry. However, the gas industry still faces environmental challenges, such as reducing methane emissions to below 0.2% of output. Sour gas is likewise seeing considerable growth – up to one third of all gas reserves contain significant amounts of H_2S. In the UAE, the drive for gas self-sufficiency – possible even becoming a gas exporter by 20205 – will see more sour gas reserves developed.

Sulphur recovery units

Abhijeet Raj of the UAE's Khalifa University of Science and Technology considered oxygen enrichment as a way of decreasing fuel gas consumption as well as increasing aromatics (BTX) destruction in a sulphur recovery unit. To minimise carbon monoxide production, enrichment of 50% was found to be most suitable for the Habshan gas plant feed.

Process control is making rapid improvement these days. Arghya Haldar of Helium Consulting described the MbOSS (Multi-application based Optimisation for Sulphur recovery System), which combines DCS data, modelling and analysis software to enhance the efficiency of a refinery sulphur block, operating in real time.

Domenica Misale-Lyttle of Industrial Ceramics presented an investigation into gas permeability through a ceramic paper insert in a sulphur recovery waste heat boiler tubesheet. The paper provides corrosion and heat protection in potentially vulnerable parts of the system such as welded joints, but concerns have been raised over gas bypass of the paper. These are seen in CFD modelling studies, but not in the field. Domenica presented the results of measured permeability tests in service which confirmed the low permeability of such tubesheet protection systems.

Tail gas treatment

Pen Lang Lo of INEOS in Singapore described actions taken to correct abnormally high amine losses in a tail gas treatment unit in South America. Investigation found the system had no regenerator wash trays, but these are expensive to retrofit, so INEOS developed *Amine Quench*, a small piece of proprietary equipment which reduces amine losses at minimal cost.

A similar troubleshooting procedure was the topic for Rizwan Masoud of KNPC in Kuwait. Here the TGTU, in an acid gas removal plant, had been suffering from pressure drop, poor reliability and higher acidic corrosion of regenerator tubes, as well as carbon deposition and tube leaks. It transpired that a burner issue upstream was generating insufficient hydrogen, which in turn was allowing an SO_2 slip. Remedial action has been changing the burner tip, adding an external hydrogen source and external passivation tank.

Emissions regulations on SO_2 continue to tighten. Consultant Mahin Rameshni looked at ways of reducing SO_2 emissions from a tail gas treatment unit, including using a low temperature catalyst and steam reheaters instead of a fired inline burner and selecting a specially formulated amine solvent instead of generic MDEA.

H_2S removal

ExxonMobil showcased its Compact Mass Transfer and Inline Separation (cMIST) dehydration and selective H_2S and CO_2 removal technology. This replaces a large absorber tower and uses an droplet generator inline to spray solvent into the gas, with a series of direction changes prior to the nozzle to generate turbulent flow that leads to good mass transfer. An inline separation step then coalesces the pregnant solution using a cyclone and drains it into a separator. According to Shwetha Ramkumar of ExxonMobil, this has the potential to replace an acid gas enrichment section, and can cope with H_2S concentrations of up 3,500 ppm.

Bart Prast of Twister BV – a Dutch company owned by Nigeria's Dangote group, described his firm's centrifugal vortex separator for hydrocarbons and hydrates which is able to remove H_2S without chemical processing. It has been used in Sarawak on a sour gas stream that is 3,500 ppm

H_2S and 20% carbon dioxide. In theory, he said, it could be used to remove carbon dioxide as well as H_2S, but that would require cryogenic separation.

Gokhan Alptekin of SulfaTrap described the SulfaTrap technology, which can remove sulphur compounds from refinery process streams to allow them to move into line with new 10ppm permitted sulphur in fuels regulations, using a regenerable sorbent. It can also be used in gas streams – tests in a biogas unit with fluctuating H_2S levels from 100 to 2,500 ppm reduced H_2S concentrations to below 10 ppm.

Lastly, Adnoc's Prachi Singh looked at one of his company's current lines of research – decomposition of H_2S to sulphur and hydrogen as part of Abu Dhabi's move to a lower carbon economy. There are various technologies available for H_2S decomposition; thermal, photocatalytic, thermochemical, biological or even electrolysis, but none are currently at a commercial stage, and some remain only laboratory concepts.

Highly sour fields

Michael Hess of Schlumberger also presented a membrane separation technology which can divide, e.g. a 21% H_2S content gas into a 4% and 65% stream respectively. The enhanced stream can then be reinjected, reducing the load on downstream gas processing systems.

In a paper which was later judged to be the best presented at the conference, Saqib Sajjad of Adnoc looked at alternatives to fuel gas for ultra-sour gas processing. Adnoc is researching using solar power – either photovoltaic (PV) or concentrated solar power (CSP) to generate steam and electricity and free up the use of fuel gas to generate more sales gas instead. The UAE certainly has the space and the sunlight, the key questions remaining are scale and of course cost. Saqib noted that the price of solar energy has fallen by 60% in the past three years, to just 2.3 cents/kWh at a Saudi PV installation in 2017, while CSP is now at 7.3 cents/kWh and could be lower (5.6 c/kWh) if only steam and not electricity were being generated. Adnoc believes that this is feasible given the cost at which sales gas can be sold for, and is now moving towards a formal evaluation and longer term adoption of the technology.

New technologies

Finally, Eric Nijveld, previously involved in technology deployment for Shell, now with his own company Deployment Matters, looked to the future with a keynote speech on technology deployment in sour gas projects. The oil and gas industry is often thought of as being risk averse when it comes to technology, he said, but this was sometimes because suppliers find it difficult to find the right people to talk to in end user companies, while end users may be keen on trying new technologies but have limited time to assess available technologies, or else feel overwhelmed with the choices available and hence fall back on conventional practices. Eric's company, Deployment Matters, aims to cut through this by providing a technology catalogue with user reviews and summaries in a similar manner to a website like TripAdvisor, along with the know-how to get the technology deployed. It can provide a matrix of a technology's status – how many other companies are using it, considering it, and rating its impact and usability. ■

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

Sulphuric acid projects 2019

Sulphur's annual survey of recent and planned construction projects in the sulphuric acid industry includes several large-scale acid plants both for phosphate processing and to capture sulphur dioxide from smelters.

Image, left: Vale's Sudbury nickel smelter, Canada.

Company	Site	Application	Capacity	Licensor	Contractor	Type of project	Start-up date
ALGERIA							
Sonatrach	Souk Ahras	Sulphur burning	4,500 t/d	n.a.	n.a.	New	2022
AUSTRALIA							
Nyrstar	Port Pirie	Smelter off-gas	n.a.	Outotec	Outotec	Revamp	2018
CANADA							
Teck Resources	Trail	Smelter off-gas	1,040 t/d	Chemetics	Chemetics	New	2019
Vale	Sudbury	Smelter off-gas	1,540 t/d	Chemetics	Chemetics	Revamp	2018
CHILE							
Codelco	Potrerillos	Smelter off-gas	n.a.	Outotec	Outotec	Revamp	2019
Codelco	Chuquicamata	Smelter off-gas	2 x 2,050 t/d	DuPont MECS	SNC Lavalin	New	2019
CHINA							
Bestrgrand Chemical	Huizhou	WSA	910 t/d	Haldor Topsoe	n.a.	New	2018
Shandong Chambroad	Shandong	WSA	419 t/d	Haldor Topsoe	n.a.	New	2020
Jiangsu Sailboat	Lianyungang	Spent acid regen	1,430 t/d	Chemetics	n.a.	New	2019
CNOOC	Hainan	Spent acid regen	700 t/d	Chemetics	n.a.	New	2019
Jilin Zirui New Material	Jilin	Spent acid regen	400 t/d	Chemetics	n.a.	New	2019
DEMOCRATIC REPUBLIC OF CONGO							
Shalina Resources	Mutoshi	Sulphur burning	3 x 250 t/d	Outotec	n.a.	New	2019
Kamoto Copper Co	Lualaba	Sulphur burning	1,900 t/d	DuPont MECS	Desmet Ballestra	New	2020
EGYPT							
El Nasr	Ain Sukhna	Sulphur burning	2 x 1,900 t/d	Outotec	Intecsa	New	2019
FINLAND							
Boliden	Harjavalta	Smelter off-gas	2,000 t/d	Outotec	n.a.	New	2019
INDIA							
Grasim	Vilayat	Sulphur burning	550 t/d	n.a.	n.a.	Revamp	2018
INDONESIA							
Sateri Intl	Kerinci	WSA	300 t/d	Haldor Topsoe	n.a.	New	2018
PT Pertamina	Balikpapan	Spent acid regen	74 t/d	Haldor Topsoe	n.a.	New	2020
IRAN							
NICICO	Sarcheshmesh	Smelter off-gas	n.a.	Outotec	n.a.	New	2018

Company	Site	Application	Capacity	Licensor	Contractor	Type of project	Start-up date
MOROCCO							
OCP	Jorf Lasfar	Sulphur burning	n.a.	Outotec	Outotec	New	n.a.
OCP	Jorf Lasfar	Sulphur burning	2 x 5,000 t/d		Intecsa	New	2021
PERU							
SPCC	Ilo	Smelter off-gas	1,450 t/d	Chemetics	Chemetics	Revamp	2018
Petroperu	Talara	WSA	560 t/d	Haldor Topsoe	Cobra	New	2020
RUSSIA							
OSC Slavneft	Yaroslavl	Spent acid regen	135 t/d	Haldor Topsoe	n.a.	New	2019
Acron	Dorogobuzh	Sulphur burning	2,100 t/d	Outotec	SNC Lavalin	New	2019
PhosAgro	Volkhov	Sulphur burning	2,400 t/d	n.a.	n.a.	New	2023
SAUDI ARABIA							
Ma'aden	Umm Wual	Sulphur burning	3 x 5,050 t/d	DuPont MECS	SNC Lavalin	New	2018
SOUTH AFRICA							
Anglo Platinum	Polokwane	WSA	148 t/d	Haldor Topsoe	Hatch	New	2020
SWEDEN							
Boliden	Ronnskar	Smelter off-gas	n.a.	Outotec	n.a.	Revamp	2019
UNITED STATES							
ioneer	Nevada	Sulphur burning	3,500 t/d	DuPont MECS	SNC Lavalin	New	2021
ZIMBABWE							
Zimphos	Msasa	Sulphur burning	n.a.	n.a.	n.a.	Revamp	2018

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

Water treatment in sulphur recovery units

As the world moves towards more sustainable processes with minimum impact on the environment, plant designers are forced to investigate new ways of meeting stringent environmental regulations. Comprimo® has developed a solution together with Cool Separations B.V., using an innovative process called eutectic freeze crystallisation for the treatment of water effluent streams originating in SRUs that are difficult to handle by conventional water treatment solutions. **T. Roelofs** of Comprimo®, **B. Brocades** and **M. Aljirjawi** of Cool Separations B.V. discuss the benefits of this technololgy.

In most refineries and gas plants, the sulphur recovery unit (SRU) plays an integral role in meeting the environmental limits of the facility. Depending on the environmental requirements, a technology licensor is typically involved in the design of these units and, depending on the technology selected, several effluent streams may have to be handled outside of the unit. Seemingly small, effluent streams such as water or a vent gas can require considerable attention in order to meet emissions requirements. With growing interest in the reduction of effluent streams to the environment, plant operators are increasingly forced to deal with any effluents streams.

Comprimo® has experienced that the design offering the highest value to the client may not necessarily be selected, particularly when effluent streams cannot be handled on site. A proposed line-up may be cost-effective but incompatible with the client's needs. Installation of dedicated treatment facilities is capital intensive adding complexity and increased plot space demand. As a result, the processing of the effluents produced by the lower cost technology could end up resulting in a much higher cost solution.

A worse scenario was encountered for a project well underway where the client discovered it was unable to treat particular effluent streams causing an inconvenient situation. When licensors offer technology it provides a perfect fit with the intent to recover sulphur. Inadequate analysis of all the battery limits at the proposal phase may, however, lead to surprises in the design phase of a project, incurring delays and requiring further hardware. In order to overcome such issues, the creation of an all-inclusive solution by the technology suppliers could result in a project with the overall lowest cost and environmental footprint.

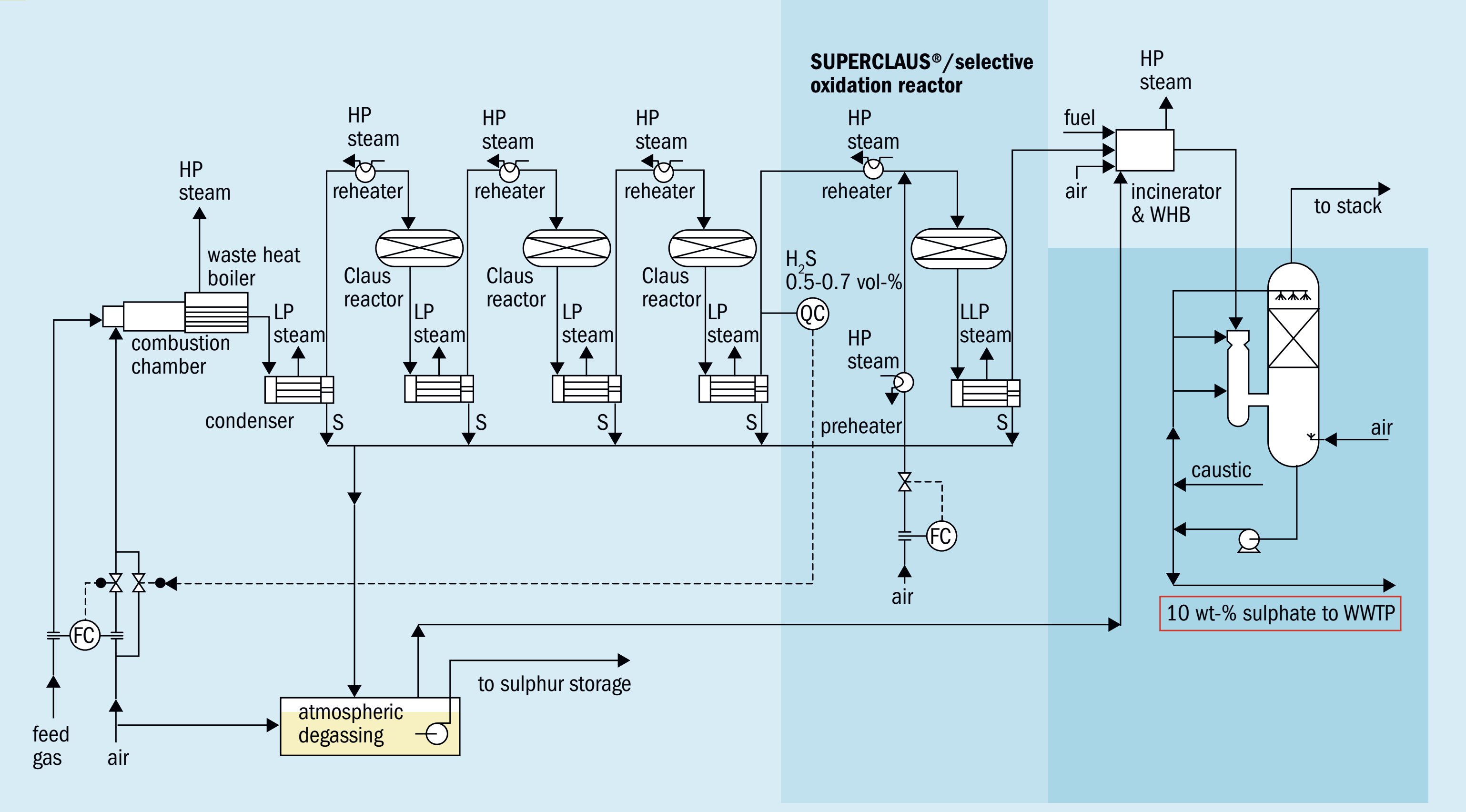
To consider providing a total solution rather than part of the solution requires a broader mindset outside the traditional boundaries of the field of technology for any technology supplier. This approach can also be found on a larger scale where the concept of a circular economy is being implemented. The use of resources generating materials or energy thereby creating waste is no longer valid. This linear way of thinking in the past has long since been overtaken by a drive towards more sustainable processes where waste materials become raw materials. This in itself drives innovation in traditional production processes and new techniques for processing of these components. In addition, this development in turn is not only pushed from a desire to minimise emissions but also to reduce the operating costs of installations. As an example, the concept of 'zero liquid discharge' not only brings about additional costs in reducing emissions, but also results in the re-use of water and minimises the volume flow of waste streams. This can be quite valuable in remote locations where water is scarce. It also changes the way we perceive waste streams as this requirement motivates the valorisation of waste streams. The re-use of water, reduction of waste streams and the recovery of resources results in a reduction of operational costs. It is logical to extend this philosophy to sulphur recovery units.

Effluent streams in sulphur recovery units

In Fig. 1 and Fig. 2 two commonly employed line-ups for sulphur recovery units are presented. The catalytic conversion processes consisting of a Claus section, selective oxidation stage, with the industry standard EUROCLAUS® or SUPERCLAUS® process, can achieve a sulphur recovery efficiency in the range of 99.0%-99.6% depending on the feed gas composition[1,2]. The remaining 0.4% to 1.0% of sulphur species is incinerated and sent to the atmosphere as SO_2. For further reduction of the SO_2 emissions, a caustic scrubber can be installed downstream the incinerator. The absorbed SO_2 from the flue gas generates a sodium sulphate solution which can be treated at the site's waste water treatment plant (WWTP).

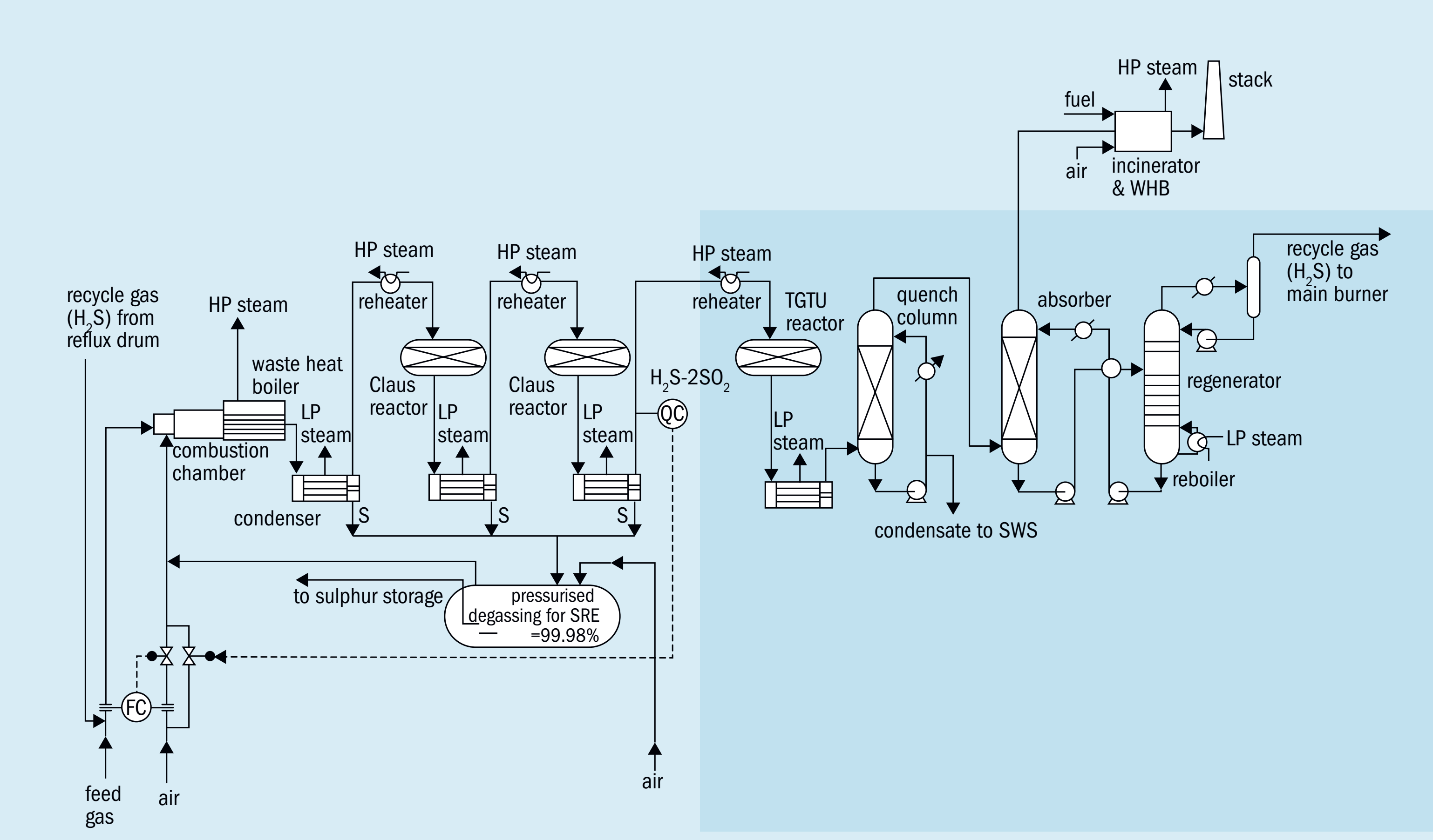
For sulphur recoveries greater than 99.5%, amine-based tail gas treating units (TGTU) are the industry standard. A typical line-up consists of a Claus section with two Claus reactor stages meeting up to 97% sulphur recovery. The remaining sulphur species in the gas are hydrogenated to

Fig. 1: **Line-up of SRU with SUPERCLAUS® + caustic scrubber**



Source: Comprimo

Fig. 2: **Typical SRU with amine-based tail gas treating technology**



Source: Comprimo

H_2S, which is captured by a selective amine-based solvent. Quenching of the gas occurs upstream of the absorber stage in order to cool the gas and remove water originating from the Claus reaction. This condensed water contains dissolved species such as H_2S and SO_2 rendering it a sour water effluent stream typically treated in a sour water stripper column. A regenerator downstream of the absorber regenerates the solvent releasing H_2S which is recycled to the thermal stage at the front end of the plant. The treated gas is routed to the incinerator which converts any remaining sulphur species to SO_2.

The configurations presented in Fig. 1 and Fig. 2 are cost-effective for sufficiently high sulphur capacities.

Other technologies entering the traditional market include the biological Thiopaq® technology, which can handle sulphur capacities over 50 t/d. This technology generates a sulphate effluent stream also requiring further treatment. There are many other technologies for lower sulphur capacities which will not be investigated in detail in this article. The line-ups discussed suffice to illustrate the effluent streams typically found within sulphur recovery units.

Typical effluent streams for sulphur recovery units include flue gas, sulphur storage tank vents, sour water containing H_2S and or ammonia, sulphate-rich stream solutions from either caustic scrubbers or a biological SRU. Most gaseous effluents do not require additional attention but the different liquid streams need consideration for disposal. Sour water coming from a quench column in an amine-based TGTU is typically treated in a sour water stripper. Most of the time such a column is available on site and this stream is added to the feed. For new design a standalone dedicated stripper column is also implemented when required.

The sulphate-rich solutions found downstream of caustic scrubbers or Thiopaq® units can be treated by waste water treatment plants (WWTP). In Fig. 1 the sulphate containing effluent stream of the caustic scrubber is highlighted in red.

Most refineries have a WWTP on site and these effluent streams add 1-5% additional capacity by volume which can in general be accommodated without any issue. Although rich in sulphate, the dilution factor of the entire feed is sufficiently high such that these streams can be disposed of. There are several scenarios however where these liquid effluent streams can pose a problem:

- Insufficient capacity or no WWTP on site – in this case the effluent stream will have to be processed off-site or a dedicated solution is required.
- Too high sulphate content – the local WWTP cannot treat the effluent stream or the concentration is too high for disposal to an external WWPT.
- Remote location – dedicated WWPT solutions are required in remote locations where the re-use of water can be of economic interest.

Insufficient or no water treatment processing capacity forces the plant operator to find a solution elsewhere. Strict compositional demands could limit processing in nearby facilities as was seen in a European gas plant where the nearby water treatment facility required a much lower sulphate content in the effluent stream.

Dilution could be a solution for lowering the sulphate content but would increase operating costs and result in a bigger overall waste stream. Removing species which are already concentrated is much easier. Preferably the components from the effluent stream such as sodium sulphate can be obtained in a pure state such that it can be disposed of more easily when serving as a raw material elsewhere. The industrial use of sodium sulphate can be found in the production of detergents, paper pulp industry (Kraft process) and in the manufacture of glass[3].

Water treatment options for SRUs

State-of-the-art water treatment options for saline waste waters are numerous (Fig. 3) but suitability of these processes will be dependent on the feed composition and the requirements for solid waste and liquid waste handling after treatment[4].

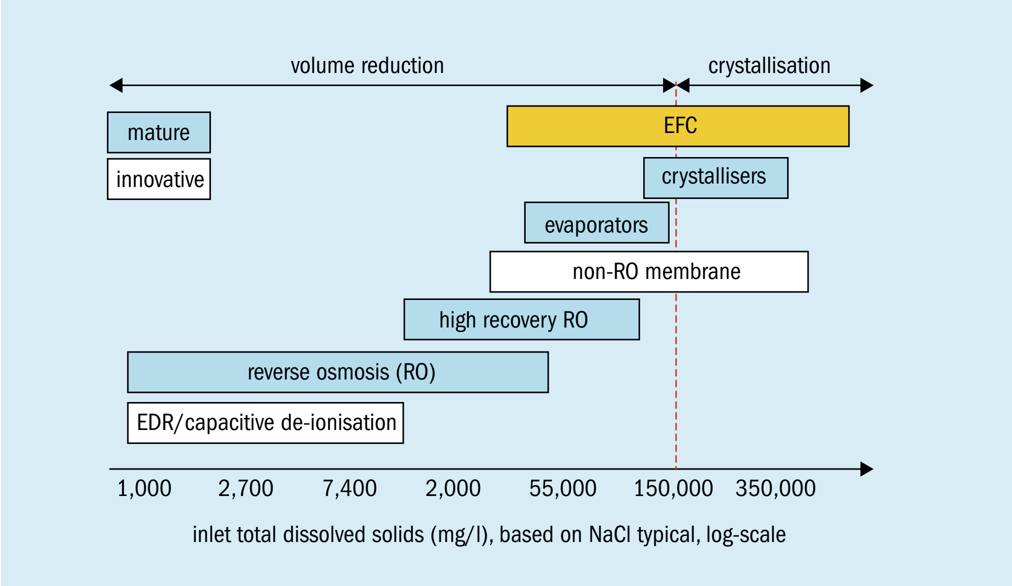
Activated sludge (AS) is a process dealing with the treatment of sewage and industrial wastewaters. AS consists of three main components: an aeration tank, which serves as bio reactor; a settling tank for separation of AS solids and treated waste water. Atmospheric air is introduced to a mixture of screened industrial wastewater combined with organisms to develop a biological floc ("activated sludge"). AS is used for the following purposes:

- oxidising carbonaceous matter: biological matter;
- oxidising nitrogenous matter: mainly ammonium and nitrogen in biological materials;
- driving off entrained gases carbon dioxide, ammonia, nitrogen, etc.;
- generating a biological floc that is easy to settle;
- generating a liquor low in dissolved or suspended material.

AS systems can handle up to about 5 wt-% of salts in the feed like sulphates and chlorides. These systems are suitable for converting organic compounds into biomass, but do not convert or separate salts fed to the process. Salts therefore leave an AS process with the waste sludge and treated water from the system rendering this technology unsuitable for treatment of a sodium sulphate-rich effluent stream.

Anaerobic biological water treatment systems can handle up to about 1.5% of salt content in the feed. In these systems

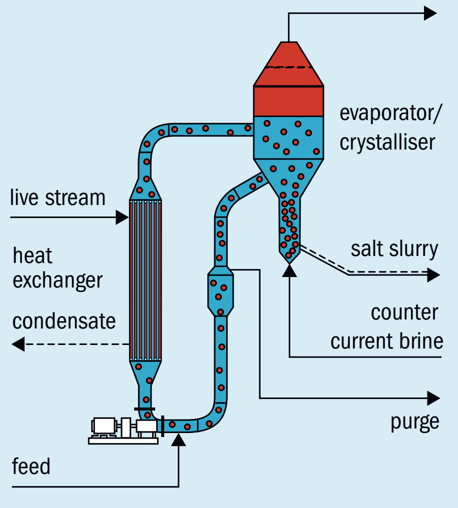
Fig. 3: **Volume reduction and crystallisation technologies for saline solutions**



Source: Cool Separations B.V.

Fig. 4: **Forced circulation crystalliser (FCC)**

Source: Evatherm brochure[6]



sulphate is reduced to sulphides which results in the metabolic inhibition i.e. poisoning of the necessary bacteria and the generation of high concentrations of gaseous H_2S, which means an additional gas scrubber or adsorption beds are required to control the gaseous sulphide emissions. Such a system is not preferred for treatment of small effluent streams in SRUs.

In case waste waters contain predominantly sodium sulphate and sodium bicarbonate/carbonate these salts could be removed by dosing milk of lime in order to precipitate calcium sulphate and carbonate as these compounds have low solubilities compared to sodium sulphate. For example, the Cost Effective Sulphate Removal (CESR) process could get the salt level down to below 100 ppm in total. Despite the relatively low hardware investment i.e. if no sludge dewatering installation is required the operational costs will rapidly rise with increasing salt levels. Apart from the direct costs, the process creates a substantial amount of additional solid waste which adds on to the overall cost of this treatment process. For every tonne of sulphate fed to the process about 800 kg of milk of lime is needed creating 1.8 t of solid calcium sulphate waste. At a hydrated lime bulk price of $150/t this would add $120/t of sulphate to the operational cost.

Reverse osmosis (RO) membrane filtration is limited in the feed salt concentrations it can handle. Feed salt concentrations of about 6-10 wt-% depending on the specific salt type are already too high to consider direct RO treatment. A combination of the CESR process followed by RO would be technically viable but adds to the cost per tonne treated.

Another alternative is a two-stage treatment plant, e.g. multi effect distillation (MED) or mechanical vapour recompression (MVR) followed by evaporative crystallisation in so-called forced circulation crystallisers (FCC) illustrated in Fig. 4[6]. The MED or MVR part evaporates water from the solution up to the maximum solubility of the main salts present at the boiling temperature avoiding crystallisation of these components.

In the FCC stage, salt crystallisation takes place allowing for the separation of salt and water. Apart from the fact that these systems are characterised by high capex and high opex costs (mainly energy costs), more waste is also generated than the original feed by having to dose antiscalants to avoid scaling of the MED or MVR systems which causes downtime for cleaning. Apart from clean water, the FCC unit generates a completely mixed crystallised salt stream. Typical electrical energy consumption for these two stage systems are about 100 kWh/t of waste water dependent on the feed composition. These systems are not easily scaled at these lower flow rates and are therefore capital intensive.

Eutectic freeze crystallisation

Another alternative is Cool Separation's eutectic freeze crystallisation (EFC) technology most suited for the treatment of highly concentrated saline to hypersaline aqueous streams. Either pure salts are separated from aqueous brine solutions or these brines are converted into pure water and pure crystallised solutes or salts all in one. As the heat of fusion of ice is six times less than the evaporation heat of water, the energy required to separate the water as ice is significantly less than that required for the separation by evaporation making EFC a highly energy efficient alternative. No antiscalants or corrosion resistant materials for equipment parts are required for this process.

The technology makes use of the difference in solubilities of various commonly known and widely appearing salt types in waste waters. Upon cooling, a number of these salts are characterised by a steep decline in solubility at temperatures unique for a particular salt making it possible to separate different types of dissolved salts up to the extent that these salts could even be reused. This phenomenon is quite different from the solubilities known at boiling temperature conditions.

A quite striking example is sodium sulphate which still has solubility in water of about 30 wt-% at boiling point. The solubility of this salt at about -1.5°C is only 4 wt-%. As a result, from an energy efficiency perspective alone, it makes much more sense to cool a sodium sulphate containing stream for clean-up than evaporation. Depending on the actual sodium sulphate feed concentration, energy requirements for cooling per tonne of feed waste water could be as low as 20% or even less of the energy required for evaporation followed by evaporative crystallisation for a complete separation of water and salt.

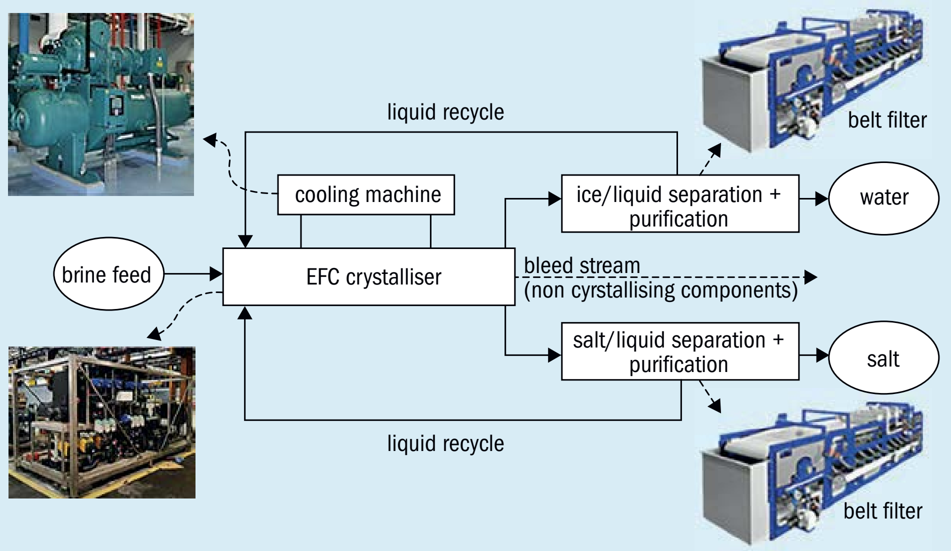
The EFC treatment plant

The main components of the EFC process shown in Fig. 5 include the cooling machine indirectly cooling the EFC crystalliser, the EFC crystalliser and belt filters for separation of ice, salt and liquid. The EFC crystalliser consists of one to as many standard segments required to cool the brine to the required low temperature. Brine entering the crystalliser will be cooled to a temperature where salt and/or ice will crystallise. The crystalliser is constructed in such a way that maximum heat transfer is provided and no ice or salt scaling effects will hamper the heat transfer.

In the case that a salt starts crystallising first, salt crystals will deposit in the solution. This renders the water in the remaining brine or mother liquor to become purer. Once ice and salt start to crystallise simultaneously, the system reaches its eutectic point at a specific temperature and specific mother liquor composition depending on the type of salt. In theory, a 100% yield of both pure salt and water can be obtained in a binary system, which is one of the advantages of the EFC technology. Accumulation of highly soluble impurities can be controlled by small purge streams.

The sludge leaving the crystalliser is first separated in a salt-rich phase and/or ice-rich phase, whereby the remaining brine phase is fed back to the crystalliser. As ice has a lower density than water the ice-rich phase is easily separated from the salt phase having a higher density than water. The salt-rich phase and the ice phase leaving the separator will now be filtered on separate vacuum belt filters. Here the ice and salt are further separated from adhering brine and washed to obtain the highest possible purity. The brine from the belt filters is fed back to the crystalliser. The cold from the streams leaving

Fig. 5: **Process flow diagram of the EFC process showing the main components**



Source: Cool Separations B.V.

Fig. 6: **Examples of modular EFC treatment skids**

Source: Cool Separations B.V.

Table 1: **Typical composition case study 1 sulphate containing effluent stream**

Origin	Component	Concentration (wt-%)	Flow (m^3/h)
Caustic scrubber	$NaSO_3/Na_2SO_4$	8-10	1.5 (normal operation)
	$NaHSO_3$	0.2-0.5	
	$NaHCO_3$	0.6-1.0	

Source: Comprimo

the process is recovered in the most efficient way possible.

EFC turnkey treatment plants in most cases can be supplied in containers or standard skids as presented in Fig. 6. As this process is modularly scalable to a high extent, it creates a lot of flexibility for capacity expansions or capacity turn down. The off-site construction and testing reduces construction time on site.

Case study 1

The use of eutectic freeze crystallisation was investigated for the caustic scrubber effluent of a plant located in China. In this case, the client was looking for a solution to meet the stringent SO_2 emission specification of 50 mg/Nm^3 set by the authorities. As the existing technology applied in the plant was the SUPERCLAUS® technology, Comprimo® was consulted to offer the best technology to reduce the emissions to the new required value. Installation of a caustic scrubber would result in the lowest investment cost for the client. However, for this particular case, the sulphate content was too high for the local WTTP. The composition of the effluent stream is shown in Table 1.

Alternatively, an amine-based TGTU could be considered. This would require a revamp of the installed selective oxidation reactor to a hydrogenation reactor and addition of the quench, absorber and regenerator section associated with a TGTU. As this option is more capital cost intensive than the addition of a caustic scrubber, finding a dedicated treatment option of the caustic scrubber effluent was evaluated first. Proven technologies capable of meeting the requirements included evaporative crystallisation and eutectic freeze crystallisation. For the evaporative crystallisation solution, treatment of the 1.7 m^3/h (normal operation) effluent stream tends to be capital intensive due to the small size of the stream. For a forced circulation crystallisation system, this capacity is in the low range.

Two types of evaporative techniques can be used for evaporative crystallisation. Thermal evaporation requires steam for evaporation as well as cooling water for condensation of the evaporated water. With mechanical vapour recompression technology more heat integration is possible by virtue of recovering the latent heat by pressurising the evaporated water with a compressor. Installation costs are twice as high

Table 2: **Indexed capex of different options**

Option	Index
Caustic scrubber addition	1.0
Revamp to amine based TGTU	3.5
Caustic scrubber and evaporative crystallisation	1.42
Caustic scrubber & eutectic freeze crystallisation	1.22

Source: Comprimo

however for this option. For this revamp project investment costs were a big driver and the thermal evaporative option was selected using steam from the plant's grid for evaporation of the water in the effluent stream. This line-up consists of a forced circulation evaporator. In the second stage, crystallisation occurs and the formed salts are removed using centrifuges.

The EFC units consist of a cooling section where both ice and salts are formed and separated simultaneously. Washing and drying occurs on belt filters after which the ice is recycled and the salts are collected.

The investment costs for this particular scenario are listed in Table 2 and the indexed data are presented in Fig. 7. The figure clearly illustrates the lower investment costs when considering a caustic scrubber for this revamp situation compared to an amine-based tail gas treatment unit. Even when considering an effluent treatment technology, the addition of a caustic scrubber remains competitive and cheaper. Plot space requirements for this scenario are also less considering installation of a single scrubber column and hardware required to treat the effluent stream compared to an amine-based TGTU. Costs for the traditional evaporative technology are relatively high for a small effluent stream.

Fig. 7: **Indexed capex for each scenario**

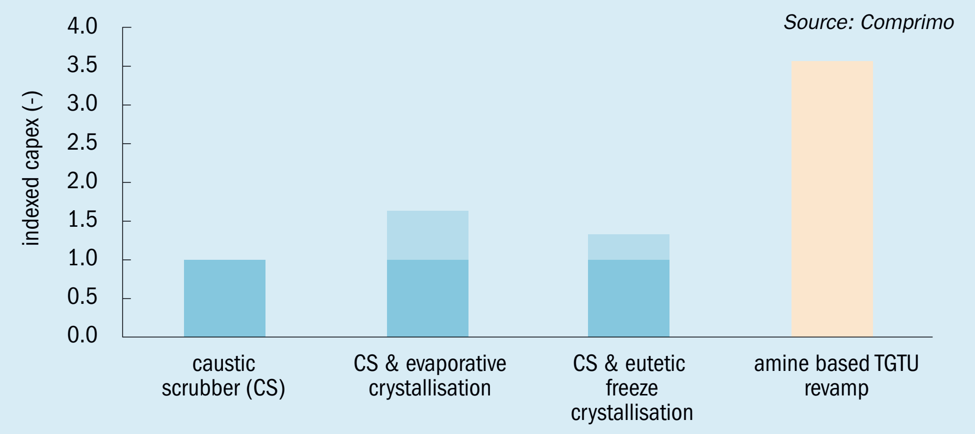
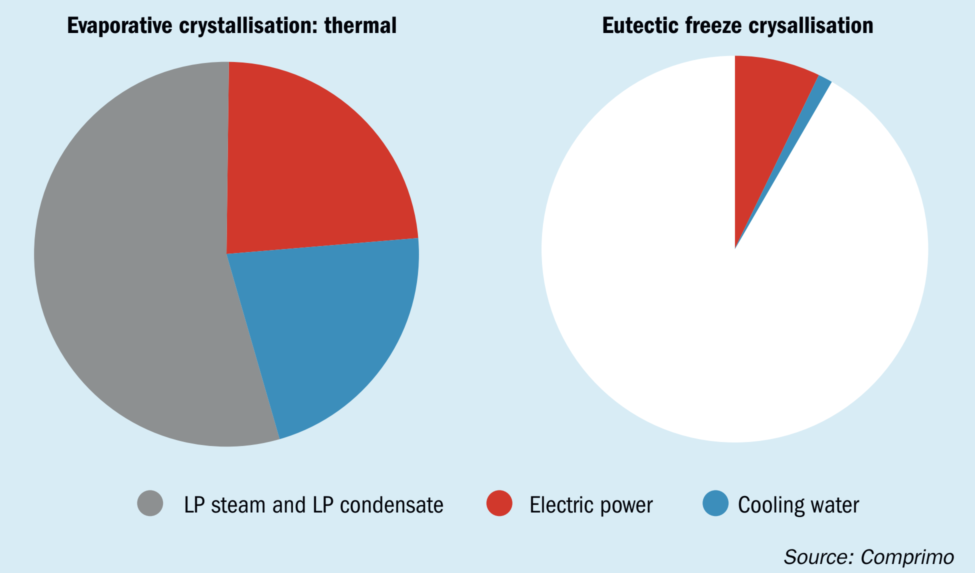


Fig. 8: **Comparison utility consumption vs evaporative crystallisation**



The efficiency and scalability of Cool Separations' eutectic freeze crystallisation allow for a fit for purpose solution with higher added value for the client.

In Fig. 8, a comparison of the operational costs of an evaporative crystalliser making use of steam and cooling water compared to a eutectic freeze crystalliser is shown. Both figures are compared to the total operating costs of the evaporative technology. It shows that in particular the costs of LP steam and cooling water drive the operational costs for the evaporative crystalliser. In comparison, the eutectic freeze crystalliser does not consume steam and only a small amount of cooling water while also having a lower energy consumption.

The numbers in this case study clearly illustrate the benefits of the eutectic freeze crystallisation technology compared to the alternative of an evaporative crystalliser. Lower investment and operational costs combined with a small footprint render the EFC process a valuable alternative to existing technologies for the treatment of the sulphate-rich effluent stream.

Case study 2

For this particular case, a gas plant was designed in a remote and dry location. Total sulphur capacity equalled 15 t/d and a Thiopaq® unit was designed for this project. No water treatment facility or fresh water supply was available on site. This meant that logistics of waste water would significantly add to the operating costs of the process and recovery of water had a high priority. Therefore, there was an incentive to recovery as much water as possible from the 1.5 m^3/h liquid effluent stream. Apart from sulphate and carbonate species, this effluent stream contained dissolved solids such as biomass and elemental sulphur (Table 3). A line-up consisting of an ultra-filtration unit followed by an evaporative crystalliser consisting of two forced circulation crystallisers was compared to a eutectic freeze crystallisation line-up. The back purge and retentate of the ultrafiltration unit is recycled back to the main process. Both line-ups comply with the zero-liquid discharge concept and valorise the recycle of water and minimisation of waste.

In Table 4, the main drivers for this case study are presented. For this project mechanical vapour recompression was the preferred evaporative technology as this reduced consumption of LP steam and cooling water for the plant. Sufficient power

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

Table 3: Typical composition case study 2 sulphate containing effluent stream

Origin	Component	Concentration (wt-%)	Flow (m³/h)
Thiopaq® effluent	Na_2SO_4	5.0	2
	$S_2O_3^{2-}$	0.5	(normal operation)
	biomass + sulphur (solids)	0.2	
	TDS	2.0	

Source: Comprimo

Table 4: Case 2 technology option characteristics

Treatment option	Capex indexed	Opex indexed	Water recovery (%)
Evaporative crystallisation	1.0	1.0	89
Eutectic freeze crystallisation	0.5	0.83	95

Source: Comprimo

supply was available. The choice for this technology affects the installed costs which increases by virtue of the compressors used for the overhead vapours. The MVR option proved to be twice as expensive as the EFC option. The benefit of MVR over a thermal evaporator is the re-use of heat for evaporation by using mechanical energy to condense the evaporated water. Exchanging heat with the feed stream allows heat to be reused. In a thermal system heat is used for evaporation as well as cooling duty for condensation of the steam. Therefore, for this technology only power is consumed. Overall power consumption for MVR is nearly twice as much compared to the EFC process.

For the evaporative option, crystalline salts are filtered from the solution and dried with air from the surroundings before being collected for transport. Cool Separations' EFC process uses vacuum belt filters, which recover more water that is recycled to the process.

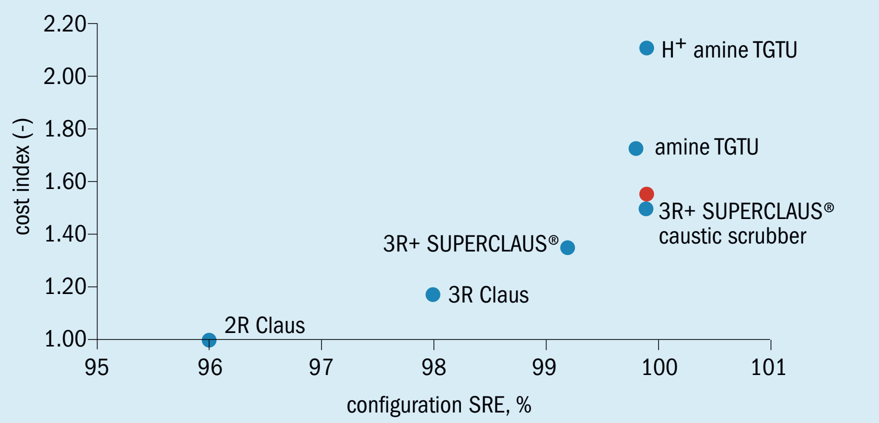
This case study again shows the value the eutectic freeze crystallisation process can offer to plant operators compared to existing technologies.

Outlook

When considering grass roots projects, the line-up with a caustic scrubber and dedicated effluent treatment can still result in a lower overall investment cost as illustrated in Fig. 9 indicated with the red dot.

This graph shows the overall investment costs as a function of the sulphur recovery efficiency. For sulphur recovery efficiencies greater than 99.8%, an amine-based TGTU typically provides a good solution.

Fig. 9: Overall investment costs vs configuration and SRE



Source: Comprimo

However, by adding a caustic scrubber to the Comprimo SUPERCLAUS® technology, a new and cost-effective alternative can be provided. Even though the treatment of the liquid effluent stream on site requires additional hardware and investment costs, the case studies have illustrated the benefit it can have for the overall project costs. In particular, when a choice is to be made between a SUPERCLAUS® + caustic scrubber option and amine-based TGTU type technology, the additional costs of an EFC unit are a lot less compared to the additional investment costs for an amine-based TGTU.

In case a sulphur specification of 50 ppmv in the stack is required, an amine-based TGTU such as LS SCOT could be considered. This is a robust and proven technology but the difference compared to a SUPERCLAUS® + caustic scrubber line-up meeting the same removal efficiency in terms of costs becomes even larger. For such cases performing a technology selection feasibility study is worthwhile.

The numbers presented in the case studies clearly illustrate the benefits of the eutectic freeze crystallisation technology compared to the alternative of an evaporative crystalliser. Lower investment and operational costs combined with a smaller footprint make the EFC process a valuable alternative to existing technologies for the treatment of sulphate-rich effluent streams. The advantage of scalability and modular design make this technology a perfect solution for the treatment of sulphate-rich streams in both grass roots and revamp situations.

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Alloy materials in sulphuric acid plants

Stainless steel and high-silicon alloys are making inroads in all areas of the sulphuric acid plant. These materials are increasing lifespan, safety, and energy efficiency both through their intrinsic properties, and through the additional flexibility they offer in equipment design. In this article, DuPont Clean Technologies and NORAM discuss strategic choices for long-term corrosion resistance and how using alloy materials for the equipment in sulphuric acid plants can benefit the producer and increase the productivity and lifetime of the plant.

Sulphuric acid plants are often considered to be permanent installations; to be upgraded and maintained indefinitely with no fixed lifetime. Indeed many plants are now in operation with no remaining original equipment. This has been made possible by a change in attitude but also by industry adoption of alloy materials in most areas of the acid plant. Alloy materials reduce corrosion and erosion, are more easily repaired and maintained, and prevent fouling products from plugging up major equipment. Alloy materials are of particular value in maintaining plants where existing equipment is being replaced, as the reduced weight and weldability can significantly reduce installation time. Also, lighter equipment can allow re-use of existing foundations despite changes in local construction codes.

The contact process used by the majority of the sulphuric acid producers in the world was developed at a time when carbon steel, acid brick and cast iron were the materials available. These materials were able to cope with some of the upsets and process variations, albeit with significant maintenance effort. The plants were also relatively small and acid temperatures were kept low to protect the equipment. As plant sizes increased new designs and new materials were developed to handle higher flows of gas and acid at higher temperatures. The use of computer programs allowed the designer to optimise process and mechanical design conditions. Advances in the development and use of alloy materials have lowered maintenance and equipment replacement costs, as well as installation time.

MECS® ZeCor® alloys for long-lasting corrosion resistance

DuPont Clean Technologies developed a family of alloys called MECS® ZeCor® – short for *Ze*ro *Cor*rosion – specifically to provide reliable, long-lasting corrosion resistance in a wide range of sulphuric acid concentrations, temperatures and applications.

MECS® ZeCor® is used in the fabrication of the complete range of sulphuric acid plant equipment from towers, pump tanks, piping systems, packing support grids, acid coolers and UniFlo® acid distributors to components and maintenance upgrade accessories such as outlet sleeves, inlet acid strainers, orifice plates, outlet acid strainers, Heat Recover System (HRS™) equipment, vortex breakers, TowerGard® mesh pads and nozzle sleeves. All equipment is manufactured in a tried and tested welding process that uses ZeCor® filler wire with welds meeting ASME code section IX standards and maintain full corrosion resistance throughout their lifetime.

All DuPont Clean Technologies components and equipment are made with the company's proprietary high-performance MECS® ZeCor® alloys including ZeCor®-Z and ZeCor®-310M. Typically, the ZeCor®-Z

PHOTO: DUPONT CLEAN TECHNOLOGIES

Installation of a MECS® ZeCor® alloy acid tower

PHOTO: DUPONT CLEAN TECHNOLOGIES

MECS® ZeCor® is used throughout the sulphuric acid plant.

and ZeCor®-310M alloys exhibit corrosion rates of less than 1 mpy (0.0254 mm/yr) under normal operating conditions in 93%-99% strong sulphuric acid.

In view of its extremely high corrosion resistance and production standards, the average life of ZeCor® equipment is more than 20 years. As ZeCor® alloys are less expensive than other alloys and comparable in lifecycle cost with traditional, less corrosion resistant materials such as cast iron and brick-lined carbon steel, it makes MECS® ZeCor® the most economic choice available.

MECS® ZeCor® alloys are available in a variety of thicknesses to match different corrosion requirements and allow for customised equipment designs. In addition, the mechanical corrosion properties of MECS® ZeCor® alloys allow for a versatile mix of fabricated acid plant components. Products can also be retrofitted to brick-lined carbon steel vessels or other conventional equipment to eliminate corrosion issues.

Designing for improved corrosion resistance

DuPont Clean Technologies sulphuric acid plant designs build on decades of experience and knowledge of what does and does not work in the real world of acid plant operation. Effective corrosion resistance not only relies on corrosion resistant materials and equipment, but on fine design details that the eye cannot see. Customising design to specific site requirements ensures organisations not only meet their corrosion protection targets, but also increase the efficiency and cost-effectiveness of plant operations while minimising the requirement for ongoing maintenance.

Take piping systems as an example. Pipes are often one of the most vulnerable parts of sulphuric acid plants. Traditional systems, made of iron, plastic-lined or merchant-grade stainless steel generally require numerous flange connections. These connections are not only at risk of corrosion, but also constitute potential leakage points which pose serious safety and environmental risks, not to mention ongoing maintenance costs. MECS® ZeCor®-Z pipes deliver ten times the corrosion resistance of cast iron systems with the corrosion rate for ZeCor®-Z normally below 1 mpy (0.025 mm/yr) in drying and absorbing tower circuits, depending on concentrations and temperatures. ZeCor®-Z piping systems require far fewer flange connections than alternative materials. This dramatically reduces acid leaks and greatly diminishes safety and environmental risks. ZeCor®-Z's high ductility also minimises the risk of brittle failure. There is less erosion from velocity compared to iron piping, so smaller diameters (available from stock or custom-sized) can be used throughout the facility. The system footprint shrinks, even as operations become more efficient, with cleaner acid thanks to a dramatic reduction in iron sulphates. The lighter weight and fully welded design of such piping systems means they are easier and more cost-effective to install, modify in situ and maintain. Pipes can be pre-spooled and shipped directly to the plant to reduce installation time and costs.

Another example of improved corrosion resistance through design choices is in mesh pads. Sulphuric acid plants using mesh pads in absorbing tower or drying tower service have long been plagued by the relatively short life of stainless steel, alloy 20 or even Teflon® mesh pads. Many plants replace such pads every two or three years, and in some cases, every year. For greater corrosion resistance, DuPont Clean Technologies can incorporate the ZeCor®-Z alloy in the design of its TowerGARD® mesh pads.

The use of proprietary MECS® ZeCor® process technology in the design of sulphuric acid plants and plant components means DuPont Clean Technologies designs not only offer consistent protection against corrosion, but also reduced maintenance costs. MECS® ZeCor® is much lighter and easier to install than brick-lined towers, which also lowers foundation costs. Reduced tower and pump tank diameters offer further savings on capital and operational costs while the fact that MECS® ZeCor® alloys are easy to weld on site by trained plant maintenance staff means these corrosion-resistance material components are also simply to repair.

NORAM design and supply of alloy equipment

NORAM Engineering and Constructors Ltd (NORAM) specialises in the design and supply of alloy equipment in all applications of sulphuric acid plants. Equipment in sulphuric acid plants must withstand challenging operating conditions from a mechanical and corrosion/erosion point of view.

PHOTO: NORAM

Assembly of a NORAM converter in SS304H.

Converters

Early converters were constructed with carbon steel shells, cast iron grids and posts, with brick-lining at least in Bed 1 where temperatures rise beyond the tolerance of the carbon steel. The vessel was exposed to an enormous mechanical stress because of the thermal expansion experienced at catalytic temperatures. High temperature corrosion caused extensive carbon steel flaking causing fouling in downstream equipment.

Today, a replacement converter is almost always constructed from stainless steel alloy material for several reasons, most notably, strength at high temperatures and a reduction in fouling products. Fouling issues could limit the effectiveness of catalyst, cause pressure drop increase, and reduce the performance of other process equipment.

Modern NORAM converters are significantly lighter because of the use of high temperature stainless steel alloy material. In modern design the alloy material, catenary plate design for the catalyst beds, and sliding supports allow the vessel to grow without causing significant stress to the structure. Its all-welded all-stainless steel construction and use of round and oval gas nozzle designs prevent gas leaks, thus, reducing maintenance repair costs, and emissions to atmosphere.

Acid towers

New materials have changed the design of acid towers significantly. Tower construction and tower internals are gradually shifting towards using high-silicon stainless steel such as NORAM SX™. Brick-lined carbon steel towers, while still the best choice in some situations, are increasingly being replaced with high-silicon alloy constructions. Particularly when replacing an existing tower, a high-silicon alloy tower provides some distinct advantages. Alloy is significantly lighter than brick, which first means that the existing foundation can usually be re-used, even in areas where civil codes have become more restrictive. Secondly, the weight and lack of any sensitive lining means an alloy tower can often be entirely shop fabricated and then lifted into place. There is no need for time-intensive bricking and shutdown durations can often be meaningfully reduced. Alloy towers are also an excellent option in remote regions where bricking labour is hard to come by or extremely costly. Moreover, alloy towers allow for less stringent fabrication tolerances to the vessel in terms of roundness.

Gas exchangers

Old, single and double segmental design gas exchangers constructed of carbon steel material are prone to sulphate fouling, and are less efficient as compared to radial flow design gas exchangers made of stainless steel alloy materials. Old designs often had aluminium diffused into the carbon steel (Alonized®) for high temperature protection. Also, the tube inlet vestibules would be metallised with a coating of aluminium. This coating had a tendency to flake off after a few years leaving the carbon steel vulnerable to the high temperature of the process. The use of 304H stainless steel eliminated the need for alonizing and metallising. Today, 95% of the gas exchangers NORAM designs and supplies are made from stainless steel.

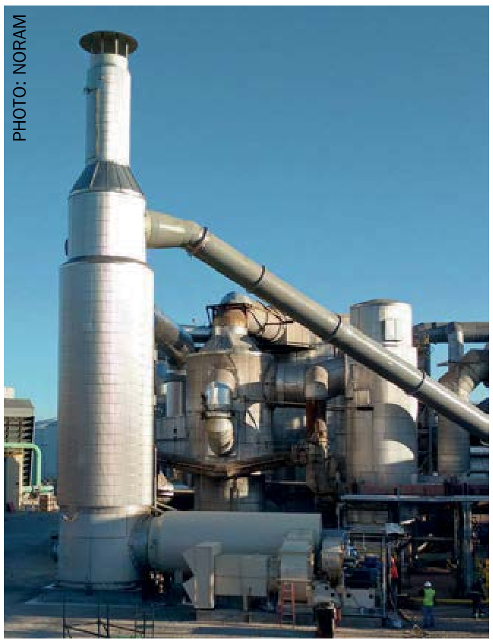


PHOTO: NORAM

NORAM preheat gas exchanger fabricated in SS304H.

The radial flow design provides even temperature distribution, thereby reducing thermal stresses. Stainless steel alloy construction offers better corrosion resistance, thus reducing the heat transfer allowance for fouling, resulting in less heat transfer area. In modern acid plants cold gas exchangers are susceptible to condensation, and thus are often fabricated in stainless steel alloy material to prevent corrosion, avoid fouling and extend exchanger life.

Gas exchanger fouling can be a significant source of pressure drop in an acid plant, and for some plants may even define the shutdown schedule as repairing a fouled exchanger is very labour intensive. Modern materials, aided further by modern designs, can reduce fouling and extend equipment life. This is especially true in exchangers which experience colder temperatures and may be susceptible to condensation. NORAM's hot-sweep design allow a slipstream of hot gases to warm up the cold tube sheet of the exchanger to eliminate acid condensation.

PHOTO: NORAM

Assembly of a pump tank (half) fabricated in NORAM SX™ alloy.

PHOTO: NORAM

Acid piping fabricated in NORAM SX™ alloy.

Acid pump tanks

Replacing a bricked pump tank in-kind and in-place is challenging. It is almost always necessary to replace in the same location and, as with towers, the bricking time is considerable. Eliminating the bricking by selecting an alloy solution can considerably shorten the installation time for a replacement tank and reduce the plant shutdown time. A modern alloy pump tank design is very durable, and with the proper design, dilution water can be added internally.

Acid coolers

Sulphuric acid plants no longer use trombone-type acid coolers with external water irrigation because they are of low thermal efficiency, high maintenance and enormous footprint. Eventually, they were replaced with the development of the anodically protected shell-and-tube acid cooler. Its introduction to the marketplace not only offered lower purchase and maintenance costs, and safety to employees, but also opportunities in plant layout designs that eventually allowed larger capacity plants to be built. For some users however, an acid cooler made from a high-silicon alloy offers some distinct advantages. Alloy coolers do not require electronic anodic-protection systems or the requisite internal cathode (a reduction in complexity is always welcome). High-silicon alloys also offer an expanded operation window, with higher velocities and temperatures possible as compared to anodic protection. The simpler design paired with the possible increase in velocity often allows for an overall smaller system for the same duty.

The use of high-silicon alloys as acid cooler material of construction is becoming an industry standard as it offers trouble free performance. NORAM offers both types of acid coolers, stainless steel with NAPS (NORAM anodic protection system), and NORAM SX™ with the number of sales for the latter growing fast.

Acid piping and valves

Acid piping is an excellent place to start when modernising a plant with alloy materials. Cast iron corrodes and erodes in elbows and areas of high velocity; both of these drawbacks are eliminated with a quality high-silicon alloy. High-silicon alloy has a much more favourable corrosion curve than cast iron and has no velocity limitation due to erosion; in fact most users find that they can go down a size in their piping diameter when upgrading from cast iron to alloy due to the possible velocity increases. Another significant improvement over ductile iron is weldability. Flanges in ductile iron piping are a significant source of leaks and may be eliminated when piping is replaced with a weldable material. This feature also allows the user to stop inventorying spare spool pieces, since alloy pipe can be easily repaired by welding.

Cast iron is susceptible to brittle failure, causing sudden leaks of hot concentrated sulphuric acid, which is a serious safety concern. On the other hand, high-silicon alloy piping such as NORAM SX™ provide a much safer system, since it is not subject to failure via brittle fracture and also has less leak points by being a welded system.

Gas ducting

Sulphate fouling products are a problem in all areas of the acid plant, and reducing the number of places where fouling can be formed is always of value. The ducting system could be thought of as the largest piece of equipment in the acid plant, and limiting corrosion in it protects all other equipment. Expansion joints in particular are at risk, where accumulation of sulphates can cause failures. In addition to reducing corrosion, stainless steel also increases the structural strength of the ducting especially at high temperatures allowing for more flexibility in design and fewer duct supports. Ducts connecting to the inlet of the converter are lower temperature and can be either carbon or 304 stainless steel. Ducts conveying gas from the converter have higher temperatures and should be made of 304 or 304H stainless steel. Ducts downstream of acid towers should be 316L to better handle acid entrainment.

PHOTO: NORAM

Acid cooler fabricated in NORAM SX™ alloy.

OXYSULF: lowering emissions

Sulphuric acid plant.

PHOTO: KVT

KVT has upgraded its wet sulphuric acid technology to improve plant efficiency and availability in various applications. Setting a new milestone in the desulphurisation of waste gases, OXYSULF is a high energy efficiency, zero waste process that achieves exceptionally high sulphuric acid concentrations and sulphur recovery rates.

KVT Process Technology (KVT) has been active in the field of environmental technology for many years, with experience in the supply of turnkey off-gas treatment plants worldwide. KVT's technologies use thermal and/or catalytic oxidation to convert all sulphur containing compounds in waste gases (e.g. H_2S, CS_2, COS or SO_2) to SO_3 and finally to sulphuric acid. Although the recovery of concentrated sulphuric acid from waste gases or waste acid is the focus, compliance with emission restrictions is always ensured.

OXYSULF technology

OXYSULF is a new technology from KVT based on the SULFOX technology concept that was developed by KVT in the 1990s. The main objective of the new design is the reduction of investment and operating costs. The OXYSULF technology produces sulphuric acid from waste gases enabling plant operators to eliminate sulphurous emissions and boost plant economics. The technology is continuously being improved and adapted to the constantly growing requirements of customers and governmental regulations.

The experience gained in sulphuric acid plant design over the last 28 years has led to many improvements including:

- new reactor design;
- new tail gas reactor concept;
- catalyst providing an improved sulphuric acid concentration;
- higher sulphur separation rate with no waste stream (pure H_2SO_4 instead of gypsum);
- controlled and safe emissions rate;
- improved reliability;
- sustainability;
- better economics.

Fields of application

OXYSULF can be applied in many different applications:

- alkylation units in petroleum refineries (H_2SO_4 regeneration);
- treatment of sour gas (H_2S);
- metallurgical industry (SO_2 off-gas);
- conventional "sulphur burning" acid plants (S);
- viscose fibre industry (H_2S, CS_2);
- chemical industry, coal gasification, natural gas processing, refinery acid gas treatment (H_2S, CS_2, COS).

Due to the wide range of applications, KVT has defined four types of the OXYSULF process. These are based on typical fields of activity, thus offering each industry a specific solution:

- OXY NK: Lean H_2S, CS_2 (e.g. viscose off-gas) and lean SO_2 (e.g. furnace flue gas);
- OXY HK: Rich H_2S (e.g. refineries, high heat release favours steam generation);
- OXY MET: "Dirty" SO_2 (e.g. metallurgical, gas cleaning necessary)
- OXY SAR: Spent acid and sulphate regeneration (e.g. various petrochemical industries).

To date, there are two OXYSULF references, one in the metallurgical industry and one in the viscose industry.

Process description

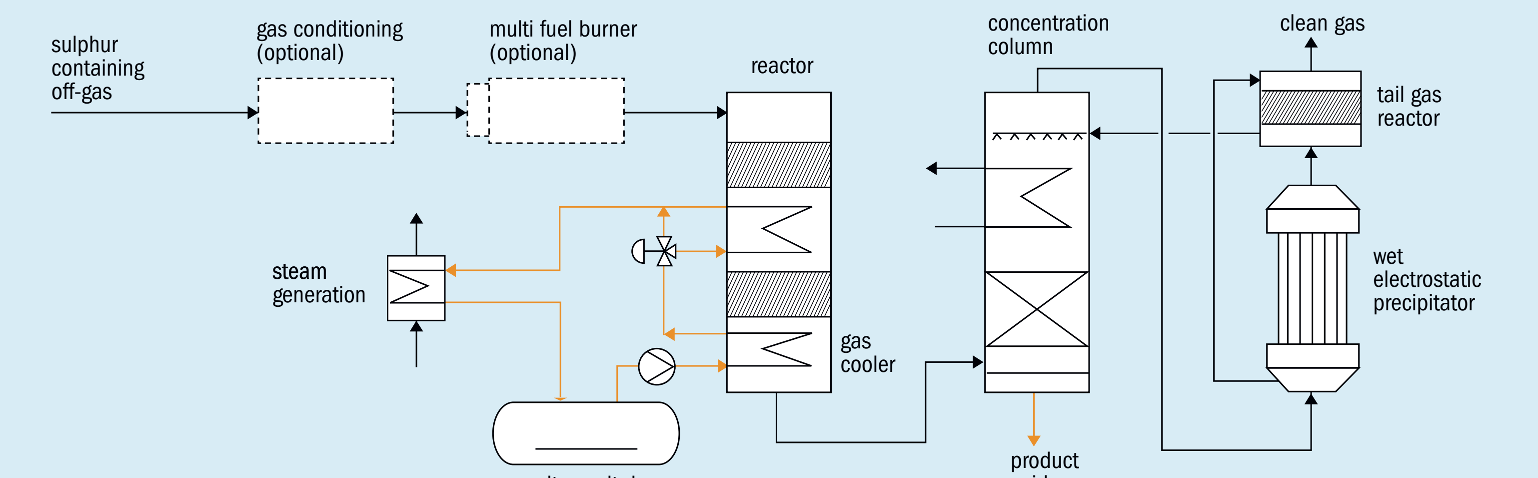
The OXYSULF process is shown in Fig. 1. First the off-gas gas is passed through a gas conditioning System. Depending on the application a combination of a prefilter, a scrubber, a Dry-Fil hot gas filter or a preheater are installed.

The pre-treatment is followed by the catalytic oxidation or thermal and catalytic oxidation, depending on the concentration of sulphur compounds.

In all cases the gas is passed over the multi-bed catalyst reactor which is followed by the condensation column and a tail gas treatment. All these steps are optimised with a heat recovery system which can even include a steam generator.

The catalytic oxidation of the sulphuric compounds is an exothermic reaction, which takes place at temperatures from 200-500°C. Depending on the raw gas composition and concentration, the raw

Fig. 1: **OXYSULF sulphuric acid process for desulphurisation of waste gases**



Source: KVT

gas is initially preheated to achieve maximum conversion rate of the SO_2. The following exothermic reactions take place:

$$H_2S + ½O_2 \leftrightharpoons SO_2 + H_2O \qquad -\Delta H$$

$$CS_2 + 3O_2 \leftrightharpoons 2SO_2 + CO_2 \qquad -\Delta H$$

$$S + O_2 \leftrightharpoons SO_2 \qquad -\Delta H$$

$$SO_2 + ½O_2 \leftrightharpoons SO_3 \qquad -\Delta H$$

$$SO_2 + H_2O \leftrightharpoons H_2SO_4 \qquad -\Delta H$$

These reactions allow for high heat recovery and lucrative steam production. After the concentration column, the gas still contains sulphuric acid aerosols. In the wet electrostatic precipitator (WESP) the H_2SO_4 aerosols are removed (aerosols <5 mg/Nm³). The precipitated acid is collected in the sump of the WESP and routed to the top of the concentration column to recover it as highly concentrated acid. A H_2SO_4 concentration of 98% and a sulphur recovery rate of 99.9% can be achieved by adding a second reactor stage. A tail gas reactor ensures lowest SO_2 emissions (SO_2 <50 mg/Nm³).

Improving plant reliability

The KVT design includes a special lining of the reactor sump and glass tube heat exchangers which are typically affected by corrosion issues. The combination of research in the catalyst field, material sciences and error evaluations have led to a new design, implementing new materials and alternative technologies such as the molten salt heat exchanging system. This enables the plant to be operated with high temperatures and pressures. Ultimately excellent energy recovery and sulphur yield can be delivered. The technology is also well suited for refurbishments or expansions and can handle various gases and hydrocarbons.

Supplying leaders in the viscose Industry

In 2019 a leading viscose producer chose to implement OXYSULF as part of their expansion plans. The project will combine waste gas cleaning and the production of 100,000 t/a sulphuric acid. The input and output streams are as follows:

Input	
Lean gas (wet):	50,000 Nm³/h
Rich gas:	400-1,500 Nm³/h
Sulphur:	1,400-2,500 kg/h
Natural gas:	500-670 Nm³/h
Output	
H_2SO_4 (>98 wt-%):	250-280 t/d
SO_2 conversion:	>99.9%
Steam:	86 bara
Clean gas (70°C):	
SO_2:	<60 mg/Nm³
Acid mist:	<5 mg/Nm³

For off-gases from viscose fibres industry the OXYSULF configuration is engineered as follows:

A multi-fuel feed burner is installed, capable of operating with lean gas, rich gas, sulphur and natural gas. The advantage of such a system lies in the in the flexibility of operation. Fluctuations in the feed gas can be compensated by sulphur burning in order to achieve constant H_2SO_4 production.

For energy recovery, a steam generator combined with the molten salt system form part of the heat recovery system.

The stream passes through platinum and vanadium catalyst beds in the reactor. The platinum based catalyst, the so-called Tardigrade operates in a temperature range of 250°C-600°C with low pressure drop. The coating of the Tardigrade is a critical part of the catalyst and requires the highest expertise, improves lifetime and reduces maintenance costs. The reactor is also equipped with interpass coolers to maintain the optimal temperature range for each specific application. Process gas cooling is achieved by a molten salt system.

In the concentration column, sulphuric acid is produced by cooling of the process gas stream. The gas stream cools down when passing ceramic packing and glass tube heat exchangers.

In the following WESP unit H_2SO_4 is separated. Lastly, a tail gas reactor ensures optimal SO_2 emissions and maximises the overall Sulphur recovery rate. The precipitated acid from both units is recycled to the concentration column.

Key features

The concentration column is the core of the entire process. Thanks to improved design, leakages and inefficient cooling are avoided and highest availability can be ensured.

By using the highest quality vanadium catalysts and KVT's specially designed platinum catalyst exceptionally long lifetime and operation flexibility is ensured.

Being a zero waste process there are no costs for waste management. The only plant outputs are concentrated sulphuric acid, steam and cleaned gas. Thanks to the WESP and the tail gas reactor the lowest emissions limits are met without the need for consumables (e.g. silicon oil, NaOH, H_2O_2 or $Ca(OH)_2$).

New hybrid sulphuric acid process

Allowable emissions of sulphur-containing gases are continually being reduced as a result of increasingly stringent environmental regulations. This has an impact on all new and operating sulphuric acid plants, where optimised operations and improved designs are required to meet the new emissions targets. NORAM and CPPE have formed an exclusive alliance and have introduced the Hybrid Sulphuric Acid Process (HSAP) to address this issue. This article presents some of the technical features of the NORAM-CPPE HSAP and discusses a number of performance parameters for industrial applications.

PHOTOS: NORAM

Examples of Sulfacid® industrial installations.

Chemical industries must evolve to remain competitive, to improve performance and to become cleaner and more sustainable. Sulphuric acid plants are faced with a number of technical and environmental challenges:

Environmental challenges: Environmental regulations worldwide have become increasingly stringent with narrower operating limits, more public awareness and increasing penalties for non-compliance. Sulphur-burning, metallurgical, acid regeneration and acid gas sulphuric acid plants are required to continuously achieving very low steady-state emissions of SO_3, H_2SO_4 mist and SO_2 (less than 50 mg/Nm³). Low emissions must also be maintained during start-up and upset process conditions. All of these environmental challenges must be achieved while still meeting commercial H_2SO_4 specifications.

Chemical integration challenges: Contact sulphuric acid technology is effective and equipment designs continue to improve. Some technologies have been proposed to improve the contact technology, however, the availability of scrubbing chemicals at the scale required is highly dependent on location and the suitability of recycling or disposal of scrubbing chemical by-products is also dependent on location. Any scrubbing processes that can be integrated to produce commercial grade sulphuric acid will therefore be attractive to operators.

Energy and efficiency challenges: Energy recovery is of great importance for the economics of plant sites and the sustainability of large scale industrial operations. Processes that offer an increase in energy recovery are therefore attractive. Acid plants can produce steam and power without emissions of greenhouse gases and there is increased interest to recover energy in steam equipment as opposed to rejection to atmosphere in SO_3 coolers. Double absorption acid plants need to re-heat process gas and require sufficient pressure to convey gas through the equipment.

Operability considerations: It is attractive to use processes that are safe and with well understood operability. Plant sites are familiar with the complexities and hazards associated with sulphuric acid handling and operation and operators,

Fig. 1: **Example of a HSAP metallurgical plant**

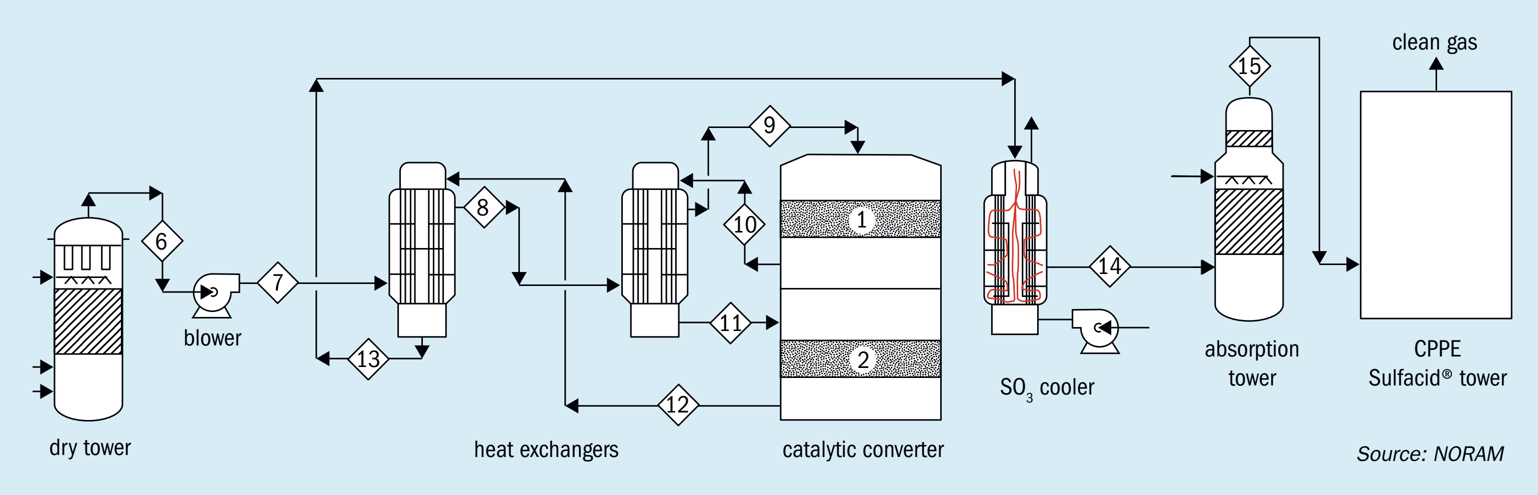
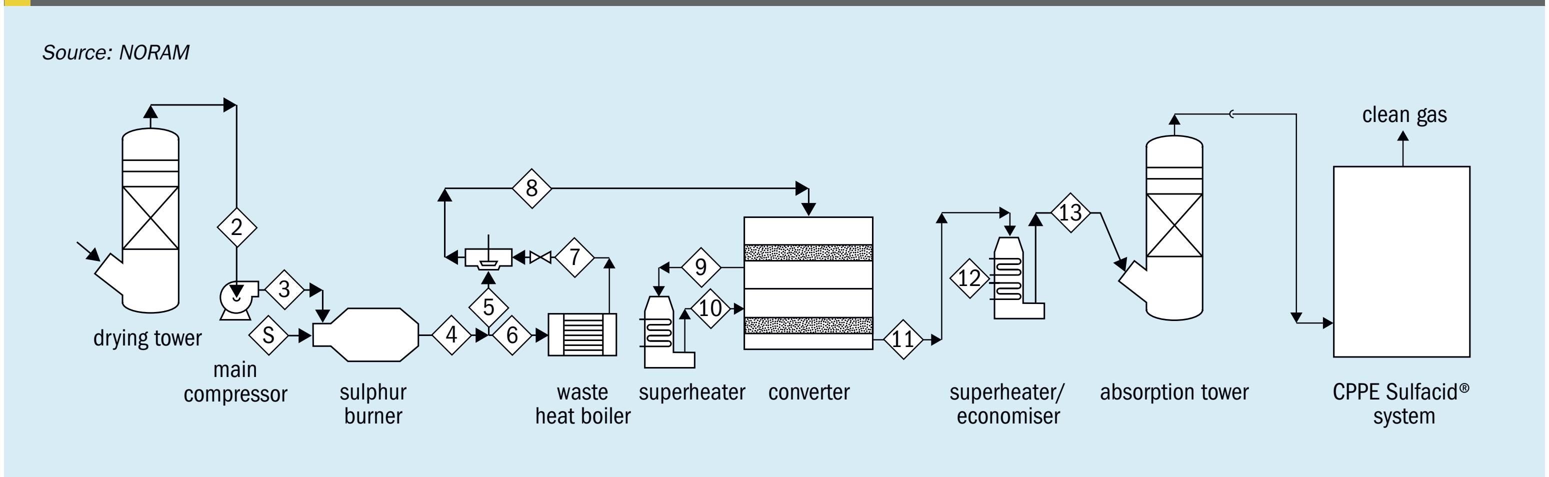


Fig. 2: **Example of a HSAP sulphur burning plant**



engineers and maintenance personnel are familiar with contact sulphuric acid plant processes and equipment.

HSAP process description

To address these challenges, NORAM and CPPE have formed an exclusive alliance to provide a comprehensive solution for the abatement of SO_2 gases in industrial applications with the development of the innovative Hybrid Sulphuric Acid Process (HSAP).

HSAP increases the production of sulphuric acid and steam while reducing SO_2, SO_3 and H_2SO_4 emissions without the need for additional reagents or increasing operating costs. HSAP utilises standard single contact, single absorption sulphuric acid technology with modern NORAM equipment designs coupled with the CPPE Sulfacid® reactor technology. The acidic effluent from the Sulfacid® reactor is recycled to the contact section resulting in a closed loop that does not require added chemicals, and does not produce waste by-products.

An example of a HSAP plant implementation for metallurgical gas is shown in Fig. 1. Process gas rich in SO_2 is fed to a dry tower system to capture water vapour. The process gas is then conveyed by the main plant blower. The SO_2 gas is converted into SO_3 by means of a catalytic converter with inter-bed heat exchange. SO_3 gas is absorbed in an absorption tower to produce commercial grade sulphuric acid. Tail gas is fed to a Sulfacid® system that ensures low emissions, allowing for simplification and savings in the conversion system.

Fig. 2 shows an example of a HSAP plant in sulphur-burning applications. Ambient air is fed to a dry tower system to remove moisture. The dry process gas is then fed by the main plant blower into a sulphur burning system to produce hot SO_2 gas. Excess heat is removed by means of a steam system for production of steam and/or power. The SO_2 gas is converted into SO_3 by means of a catalytic converter with inter-bed cooling. SO_3 gas is then absorbed in an absorption tower and then processed by a Sulfacid® system. Fig. 3 depicts the acid system of a HSAP plant. Diluted acid is produced by the Sulfacid® process.

The Sulfacid® system is shown in Fig. 4. The raw gas to be treated flows through an activated carbon catalyst fixed bed inside the reactor. The SO_2 is converted into sulphuric acid by wet catalysis in the presence of oxygen and water. The water-saturated clean gas discharges to atmosphere via a stack. The sulphuric acid collected in the pores and on the surface of the catalyst is intermittently washed out by spraying water over the catalyst. Clear industrial grade sulphuric acid flows into a buffer tank. The conversion of sulphur dioxide to sulphuric acid takes place on the catalyst with high efficiency.

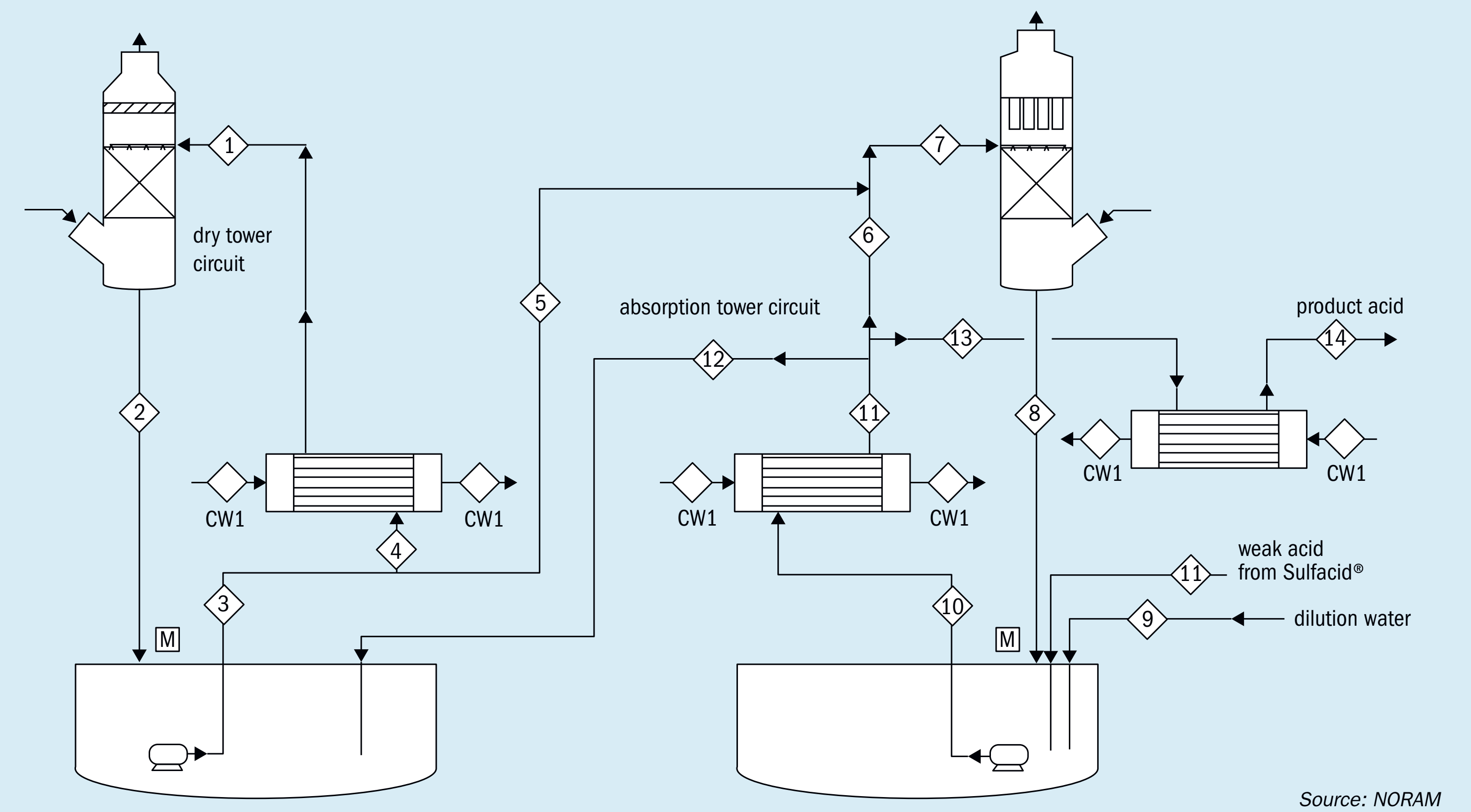
Features and advantages of the HSAP

HSAP has the following benefits and features:

- the plant design can be adjusted to meet tight emission standards;
- the system can tolerate process fluctuations while maintaining low emissions;
- no gas re-heat required, resulting in higher energy recovery from the process gas;
- the gas system has lower pressure drop, which can be realised as blower power savings or for capacity increase;

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

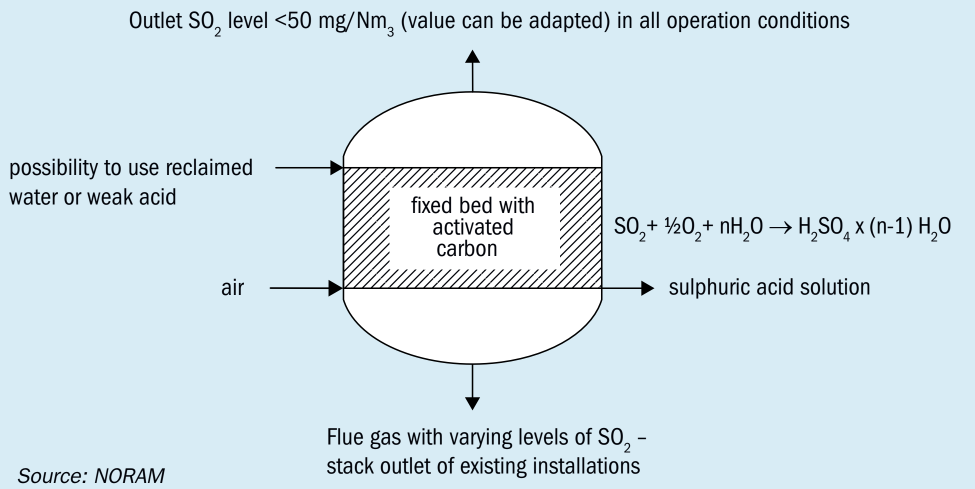
Fig. 3: **Example of the acid system in a HSAP plant**



Source: NORAM

- no scrubbing chemicals are required. The Sulfacid® system is catalytic and does not consume chemicals;
- long life of activated carbon catalyst;
- no byproducts are produced;
- dilute acid product from the Sulfacid® system is fully utilised in the contact plant as dilution feed.

Fig. 4: **Sulfacid® process**



Source: NORAM

Project implementation

HSAP is offered as a single integrated system. CPPE-NORAM can provide the complete HSAP plant and make the necessary modifications in the contact plant, providing one single interface for the client and a single guarantee for the complete hybrid system.

HSAP may be applied to new facilities or retrofitted to existing plants and will achieve lower SO_2 emissions than those of double absorption systems on a par with other off gas treatment options. HSAP has very low operating costs, low maintenance requirements and is easy to operate. Minimal operator training is required and the technology and equipment are well known to plant engineers and operators.

The plant can be designed to be ready for future emission regulations. Should environmental regulations require further emissions reductions after installation, additional Sulfacid® activated carbon catalyst can be added to the equipment, within reason, without major cost impact or down time.

In addition, the system is able to cope with fluctuations in concentrations and flow offering operability and environmental benefits to the plant. Due to the absorption "sink" provided by the activated carbon of the Sulfacid® process, HSAP in less sensitive to fluctuations in SO_2 load which may occur due to process upsets and will achieve reduced start-up emissions, allow for faster start-up times and is able to accept a wider range of SO_2 concentration without impacting the plant emissions.

Industrial installations

NORAM and CPPE have extensive track records in the implementation of sulphuric acid technologies in large industrial installations.

Acknowledgement

This article is based on a paper by Andrés Mahecha-Botero of NORAM Engineering and Constructors and Alain Strickroth of CPPE Carbon Processing & Plant Engineering S.A. et al that was presented at the AIChE Clearwater Conference 2019.

The grandfather of the Claus process

Incorporating latest research[1], **Bernhard Schreiner** of Linde recounts some of the milestones of Carl Friedrich Claus' journey through life providing some historical and technical background, but focusing on his most famous invention – sulphur recovery from H_2S.

Carl Friedrich Claus was a first child, born 9 November 1827 into a postmaster's family living in the Hessian town of Kassel, located in the geographic centre of today's Germany. In 1832 the Claus family moved a short distance to the little town of Schmalkalden, also in Hessia, which at that time was one of the many small autocratic states constituting the patchwork rug of independent territories called Germany. In the second quarter of the 19th century this backward-looking political set-up was increasingly challenged by a democratically-oriented unification movement, finally culminating in widespread revolutions popping up all over Germany around 1848.

This turbulent time should not be overlooked when reflecting on Carl's childhood and youth which fell exactly in that period. Furthermore, at the tender age of six, personal tragedy met Carl and his family in 1833 when his father Christian Claus died, leaving behind a pregnant wife with three little children. Thereupon, Carl's widowed mother Elise together with her two sons and two daughters left Schmalkalden and moved to Marburg. Here in late 1846 Carl enlisted at the local university as a chemistry student, Professor Robert Bunsen being among his teachers at this time-honoured and highly respected Hessian institution. This timing also meant that he was a student at a time of heightened political unrest before and during the breakout of widespread revolution in 1848.

Interestingly, early in 1848, Carl temporarily left home and set off for North America; however, little is known of his whereabouts and activities there or of the motivation for his apparent run-away action. In any case, it appears reasonable to assume that he was evading his sovereign's grasp; i.e. either dodging the officials' drafting activities, keen to strengthen the military contingents – or the young student was on the authorities' proscribed list, e.g. as a suspected activist. Whatever the case, Carl returned to Marburg later that year resuming his studies at least until 1850.


KAISERLICHES PATENTAMT

AUSGEGEBEN DEN 20. AUGUST 1883.

PATENTSCHRIFT

— № 23763 —

KLASSE 26: GAS-BEREITUNG UND -BELEUCHTUNG.

CARL FRIEDRICH CLAUS IN LONDON.

Verfahren der Reinigung von Leuchtgas mittelst Ammoniakgas.

Patentirt im Deutschen Reiche vom 30. Januar 1883 ab.

Fig. 1: In 1883 Carl was granted his first patent on the Claus Process in England and Germany.

Until then and beyond he could hardly have failed to observe a whole raft of disheartening developments such as the cancelling of Hessia's liberal constitution and the lack of progress as regards the modernisation of this agriculturally-oriented electorate. Seemingly, largely deprived of justified hope and in view of realistic opportunities for personal development in terms of wealth and social status, Carl finally decided to leave his home country. But unlike many other European emigrants of the mid-19th century – the so-called Forty-Eighters, tens of thousands from Germany alone – Carl didn't opt for North America but went to England, which was closer, known to be liberal and open to modernisation.

His presumed acquaintance to fellow students from Great Britain such as the Englishman Edward Frankland (chemistry) or John Tyndall (physics) from Ireland who were also enlisted at Marburg University around 1848, are among those likely to have influenced Carl's choice. Carl left the continent in 1852 at the age of almost 25 to arrive in Liverpool; soon after he applied for English citizenship, stating manufacturing chemist as his profession. Notably, even though Carl's move abroad was an ultimate one, he continued to keep bonds with Germany which is indicated in many ways; e.g. he later sent his younger son Carl Friedrich Claus Jr to study chemistry at Munich.

Not long after his arrival in England, young Carl married his first wife Mary

Brown who came from Yorkshire and eventually would be the mother of all five of his children, three daughters and two sons. The eldest, Pauline, was born in 1855 when the English citizenship was granted to her father. Remarkably, in 1860 Carl had to serve some time in a Lancaster prison as a debtor, i.e. at a time when he had a young family; clearly, his early years in England must have been quite difficult, thus exposing the family to considerable ordeals.

Throughout the time Carl grew up in Germany, he had been living in the relatively small electorate of Hessia. After leaving Germany for England, however, he became much more geographically mobile; there are at least 11 places spread over England where he was registered as having been a resident. Such mobility is in line with one of his patents where Carl stated consulting chemist as his profession, strongly suggesting freelancing activities.

A good part of Carl's professional work was related to subject matters arising from coal processing, the most prominent being the Claus process he invented. Initially, the latter was an answer to the challenge of having to deal with gases containing substantial amounts of H_2S being generated at gas works when acidifying solutions containing dissolved ammonium sulphides. Carl's groundbreaking approach was a continuous gas-phase process based on the oxidation of such H_2S gases by admixed air over solid catalyst particles in a fixed bed – the latter "dry reaction step" was followed by separation of the thereby yielded sulphur vapours from the process gas by cooling, leading to condensation and subsequent solidification of elemental sulphur, all based on

$$H_2S + ½O_2 \text{ (air)} \rightarrow 1/x\ Sx + H_2O \quad (1)$$

Even though reaction (1) is just a partial oxidation, it is quite exothermic which comes with several implications. Firstly, it means that with increasing H_2S concentration in the feed gas the temperature of the catalyst mass also rises, easily reaching unacceptably high levels which is not helped by the adiabatic reactor concept allowing for dissipation of the reaction heat only by radiation. Rising temperature also shifts the equilibrium (1) ever more to the left thus reducing the efficiency of the H_2S conversion. Besides other detrimental effects like e.g. speeding-up catalyst deactivation, when dealing with substantial H_2S concentrations in the feed gas (i.e. starting in the single digit vol-% range) as reported for early applications, the described temperature rise could only be controlled by applying extremely low space velocities; typically 2-3 $Nm^3/h.m^3$ of catalyst, an operation mode which comes with a markedly low productivity.

However, notwithstanding this severe disadvantage, Carl's process soon found increasing application and was developed further; e.g. it was not long before the ore bauxite substituted iron oxide as a catalyst. The latter modification was in use for sulphur recovery from hydrolysed CaS, a troublemaking waste material generated by the LeBlanc soda process. The success of Carl's invention is reflected by the widespread acceptance of its dubbing as the "Claus Process", a name which is first documented in a patent from 1898 with Carl being among the inventors.

From an economic perspective, at the close of the 19th century the production of sulphur based on chemical processing probably came with some profitability. Sicily, with its substantial and quite easily accessible deposits of natural sulphur, had been enjoying an uncontested monopoly in sulphur trading for some time, assuring that the price was kept at a premium. However, it is not clear to what extent Carl's rise to wealth is connected to providing the license for his sulphur recovery process, as he also held several other patents of potential economic relevance – e.g. on an improved method for the production of zinc sulphide and barium sulphate, the basic constituents of a non-toxic white pigment being the essential ingredient of a versatile type of colour which is still in use today ("lithopone").

Soon after the turn of the century, having been a widower for two decades, Carl remarried at the age of 72. As the marriage certificate reveals, his second wife Caroline Barry was his junior by 24 years and the couple had already been living together for some time. The marriage lasted a mere 10 weeks before Carl passed away on 29th August 1900 in Gunnersburry, Middlesex, bequeathing to his widow "various houses". Without doubt, German-born Carl left this world not only as an Englishman but also as a well-off businessman.

Fig. 2: A modern variation of the old Claus process.

Nowadays the modern variations of the old Claus process (H_2S direct oxidation processes) find comparably limited application for the desulphurisation of lean feed gases. Fig. 2 shows one such example for treatment of biogas high in H_2S.

Of course, Carl's Claus process relying exclusively on the catalytic oxidation of H_2S did not vanish with the inventor, but for a further three decades all efforts to significantly improve its very restricted productivity, e.g. by feed gas dilution, failed. In the early 20th century, however, technologies emerged in Germany allowing for mass production of commodities like e.g. ammonia or synthetic liquid fuel, based on vast amounts of synthesis gas made available through coal gasification. These developments in turn triggered and spurred other new technologies, appropriate to tackle implicit challenges such as the purification of the intermediate "syngas". Important here was the separation of the acidic components which was eventually solved and realised by applying liquid scrubbing, which in turn yielded acid gas high in CO_2 and H_2S (usually well into the 2-digit-% conc.).

As respective acid gas volumes were unusually high, the old Claus process with its flow limitation was no option for sulphur recovery here. When German "I.G. Farbenindustrie AG" went to work at the beginning of the 1930s to solve this problem it soon became clear that the solution must be based on the old Claus process in terms of its basic concept, i.e. "partial oxidation of H_2S by molecular oxygen and subsequent separation of the generated sulphur by condensation" and the use of a catalyst for generation of sulphur at a quite low temperature level to exploit the thermodynamics for process optimisation. Crucially, the pivotal clue was to add a thermal stage with an open flame burner at its heart upstream of the catalytic section to combust one third of the H_2S according to:

$$3H_2S + 1\frac{1}{2}O_2\ (air) \rightarrow SO_2 + H_2O + 2H_2S \quad (2)$$

A boiler was then attached downstream of the respective furnace chamber to recover most of the heat released by this highly exothermic oxidation (2) in the form of steam. The thereby cooled process gas entered the catalytic stage where H_2S and SO_2 in a ratio of 2:1 were reacted to give elemental sulphur according to:

$$2H_2S + SO_2 \rightarrow 3/xSx + 2H_2O \quad (3)$$

This so-called "Claus reaction" (3) is moderately exothermic, allowing the respective equilibrium to be shifted to the right by applying a minimised temperature level. All in all, this combined approach increased the H_2S conversion efficiency to 92-94% which was clearly superior to Carl's old process characterised by performances of up to 80% only.

Certainly more important at that time, due to the innovative concept coming with significantly reduced heat release within the catalyst material, respective space velocity could be increased by two orders of magnitude which allowed for realisation of highly productive plants. Based on a H_2S concentration in the feed of >15 vol-% the latter could produce as much as 40 t/d of sulphur.

Remarkably, the inventors succeeded in building and operating units of that calibre in Germany as early as before the second world war and dubbed this truly revolutionary technology as "Improved I.G. Claus Process" – later on for many years being called "Modified Claus Process" – obviously because the concept was modelled quite closely on Carl's invention from half a century earlier. A thermal stage combined with a subsequent catalytic section applying inter-step cooling between respective reaction steps is still the backbone of today's Claus process. The impressive potential for improvements in terms of scale-up and increased efficiency of this basic set-up over the years has allowed it to keep pace with the ever rising challenges that come with soaring industrial development, including ever more demanding environmental regulations. Nowadays, sulphur recovery efficiencies of well above 99% – up to a staggering 99.99+% are achieved on a big scale[2].

Overall, looking at the mere fragments we know about Carl's life today, one would wish more of it to be recovered from the mists of history. However, considering the tremendous importance of today's Claus process as the "sulphur recovery workhorse" in our modern world it appears that the impressive success story of Carl Friedrich Claus Sr is still ongoing and is likely to continue for many years to come. ■

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