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New sulphur from the Gulf

Sulphur as a fertilizer

Acid from non-condensable gases

Lean acid gas processing

Cover: *Aerial view at night over Prague. Taiga/shutterstock.com*

Gulf sulphur

New production from refineries and sour gas plants.

TGTU recommissioning

Re-starting a tail gas treatment unit in Libya.

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REGULARS

Editorial

A new direction for copper?

On January 25th, a tailings dam at the Vale iron ore mine at Brumadinho, Brazil, collapsed, releasing a flood of mud and slurry that buried mine workers and people in two nearby villages. Over 170 people are confirmed dead, but a month on from the terrible event, another 140 remain missing, and are also presumed lost.

The disaster has prompted a major re-think in the mining industry about its practises, especially as regards construction and use of tailings dams – the dam was an 'upstream' dam, using sediment from the tailings to build the dam wall. Worldwide, the volumes of mine tailings are increasing as ore grades fall, leading to more rock having to be processed, and as the mining industry continues to expand to feed demand in industrialising countries. But climate change is also simultaneously leading to more severe rainfall, which can undermine such dams. As a result, collapses are unfortunately becoming more frequent – Brazil is still litigating one from 2015 at Mariana in Minas Gerias state, which killed 19 people. Chile, Peru, and now Minas Gerais state in Brazil have all banned upstream dams, and Minas Gerias has ordered the decommissioning of the upstream dams still in place in the state by 2021.

> **"The industry might need to consider "fundamental change".**

Both Brumadinho and Mariana were iron ore mines, but the copper and nickel industries also make extensive use of mine tailings. Worldwide, there are reckoned to be 3,500 tailings dams. Meeting shortly after the recent incident, the International Council on Mining and Metals (ICMM), a London-based industry group consisting of CEOs of 27 of the world's major international mining companies, said that it had formed an independent panel of experts that will set international design and maintenance standards for dams and study ways to reduce the volume of water stored behind the dams in waste rock. The standards will be based on a review of current best practices in the industry, including key aspects such as a global and transparent consequence-based tailings facility classification system, with specific requirements for each level. The standards would also establish a scheme for credible, independent reviews of tailings facilities, as well as requirements for emergency planning and preparedness, according to ICMM. They will also apply to all ICMM members, regardless of location – previous recommendations have taken a more tailored approach.

However, looking to the longer term, ICMM said in its statement that the industry might need to consider "fundamental change", and possibly a large-scale switch towards in situ mining; pumping a dilute acid solution underground to leach out copper and other minerals, eliminating the need for tailings dams completely.

In situ leaching using sulphuric acid is already used extensively in uranium production, but more widespread adoption by the copper industry could signal a major change for the way that the metals industry uses sulphuric acid. Most mined copper still consists of sulphide ores, which are smelted to recover the ore, generating sulphur dioxide usually recovered as sulphuric acid. However, most copper deposits are actually oxide ores, which are amenable to acid leaching. As these are usually lower grade than sulphide ores, there has traditionally been a cost penalty to their recovery, which has restricted the uptake of copper leaching. However, in situ leaching has the potential to overcome these disadvantages. Although in situ copper leaching has a long history, there has not been large scale use because it requires a level of porosity in the rock, but attitudes are beginning to change as the technology advances, assisted by developments in the oil and gas fracking industry – 3D seismic modelling, horizontal drilling and computer controlled drill bits. Fracking processes can also be used to create artificial porosity in the rock where it does not exist naturally. By the end of this year, Excelsior Mining will be using in situ copper leaching at the Gunnison Copper Project in Arizona, with extraction costs projected at just $0.70/lb of copper; lower than for traditional open pit mines like Grasberg or Escondida.

At the moment, smelting of copper sulphide ores generates around one third of the world's sulphuric acid, while leaching of copper oxide ores consumes around 10% of sulphuric acid production. A switch towards in situ leaching of copper could thus have a major effect on the sulphur and sulphuric acid industries.

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 prices remained soft through most of February, marking the fourth month of consecutive price drops. The en d of the month saw a slight uptick in pricing, met by the market with mixed views as uncertainty prevailed on price direction. The downwards trend had been expected to reach a floor and rebound, but with the absence of meaningful spot interest from China for several months, there was no reprieve even after reaching the end of the Chinese Lunar New Year celebrations.

Middle East price postings continued to reflect decreases for February with major producer KPC in Kuwait also joining the list of suppliers announcing monthly prices from the start of the year. Sluggish demand from buyers left February prices to drop from January levels, but March reflected a turning point, signalling a firm to stable short term outlook. Muntajat announced its March Qatar Sulphur Price (QSP) at $108/t f.o.b., a $1/t increase on February. This was in alignment with the latest sale tender for a March cargo in the high $100s/t f.o.b.

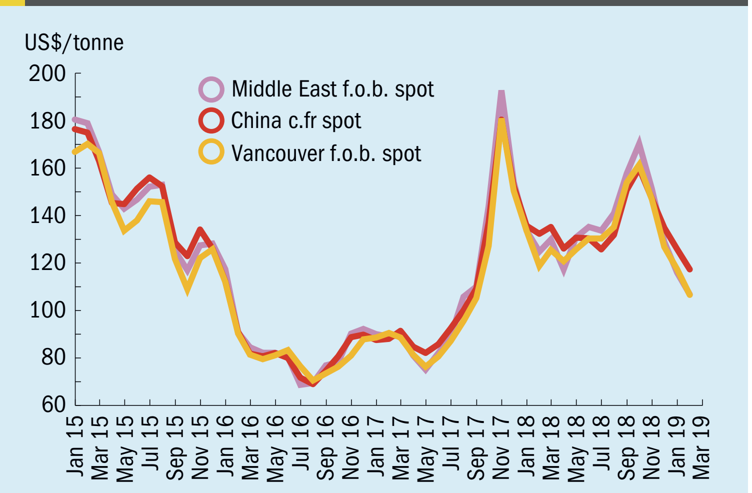
First quarter prices in North Africa were pegged at $103-134/t c.fr with the top end reflecting Middle East supply to Tunisia and the lower end of the range supported by crushed product and smaller shipments. Second quarter contract talks were set to begin from mid-March between end user OCP and its suppliers. Price direction was unclear due to the uncertainty in the market. Elsewhere in Africa, Foskor's sulphur import demand was hampered by issues at its sulphur burner at Richard's Bay at the end of February. Sulphur demand in the DRC is set to rise with the start-up of Glencore-owned Kamoto Copper Company's (KCC) new sulphur burner from the end of 2019/early 2020. This is for its Katanga leaching operations and will lead to a reduction of sulphuric acid imports from Zambia.

The downward trend in the market has been broadly attributed to the absence of Chinese buyers in the spot market in recent months, with holidays stalling interest. Spot prices in China dropped through February before seeing a slight rebound to $105-128/t c.fr at the end of the month. This represented the first positive price momentum since October 2018 and led to speculation of a market floor – a sentiment mirrored in the stable to firm pricing announced by Middle East producers for March. The extent of the price recovery may be short-lived, with reported weak outlook for the downstream processed phosphates market putting a ceiling on price expectations in the short term. However, if Chinese buyers resume purchases in earnest, low availability may drive up pricing. On the trade front, customs data shows 2018 imports at 10.7 million tonnes – a drop of 4% year on year. Imports below 11 million tonnes were last reported in 2014. The dip has raised questions around the influence of the rise of domestic sulphur production on import demand in China. Argus continues to forecast growth in sulphur recovery from both the oil and gas sectors in the country, while demand is not expected to see the same rate of growth due to the slowdown in the fertilizer sector. The influence of sulphuric acid production is also a factor – due to the rise of copper smelter capacity in the country, this may also offset some sulphur purchases. Any downward shift in imports would mean global suppliers would need to look at alternate markets to export to, a potentially bearish long-term factor for the market.

Over in India, prices continue to track international developments, with significant drops in pricing in the early weeks of 2019. At the end of March prices were assessed by Argus at $115-120/t c.fr – around $30-35/t below levels at the start of the year. Indian import demand strengthened in 2019, tallying just below 1.28 million tonnes – this represented a 13% increase on 2017 levels. Middle East suppliers dominate Indian trade, with the UAE ranking first, shipping just under 0.5 million tonnes for the year, surging 149% on a year earlier. The top spot was previously Saudi Arabia, which shipped just 131,000 tonnes in the period. This increase in Indian imports has come despite the rise of domestic Indian production, including Reliance's Jamnagar project.

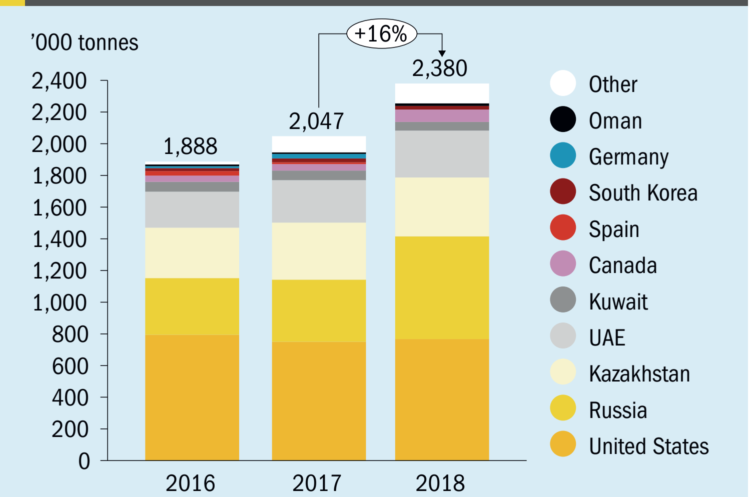
North American sulphur prices softened in line with global price trends, with major exporters impacted by China's absence from the market. Vancouver sulphur prices were stable at $98-198/t f.o.b. at the end of February. This compares to prices a year ago at $125-130/t

Fig. 1: **Global sulphur prices, Jan 2015 to Mar 2019**



Source: Argus Media

Fig. 2: **Brazilian sulphur imports, 2016 to 2018**



Source: Argus Media

f.o.b. Alberta's expected fall in supply is also expected to provide strong sentiment to pricing as the mandated crude oil production cuts run until the end of March. US Gulf prices were expected to dip below $100/t f.o.b. levels in new business in March, but the stable to slightly firm sentiment from China and the Middle East may lead to prices remaining above this level in the short term. On the domestic front, supply in the US market was deemed tight in February due to refinery turnarounds.

SULPHURIC ACID

Global sulphuric acid prices eased slightly in some regional markets in February following a long upward trend. The NW European spot acid export price corrected by $5-10/t to $80-85/t f.o.b. on the back of a slight slowdown in spot interest and low bids.

Smelter acid producer Korea Zinc carried out maintenance at Onsan/South Korea in the aftermath of a fire on 15th February. The outage was expected to last a few days, leading to a minor disruption to acid supply. South Korean exports in 2018 reached a record high of 3.01 million tonnes. China remained the leading market for this acid, while shipments to India and Chile increased by 24% and 157% respectively to 518,000 tonnes and 390,000 tonnes.

Acid prices in India dropped to US$85-95/tonne c.fr in February, with little spot demand set to emerge in the short term due to key end users taking turnarounds, including Coromandel at its Vizag and Kakinada plants in March, PPL Paradip in April, Iffco Paradip and FACT Kochi in April. The ongoing closure of Vedanta Sterlite's Tuticorin smelter in India remains a key factor for the short term supply balance and supports import demand.

Chile remained a bright spot for import demand through 2018, with prices trending up to reflect this. Acid imports for the year totalled 2.8 million tonnes; up 32% on 2017 levels, and highlighting the surge in demand that buoyed pricing across key supply regions. Prices firmed further at the start of the year through February up to $135-145/t c.fr by the end of the month. This is around 50% above price levels a year earlier. Imports are expected to remain robust through 2019, supporting pricing in the short term at least. Looking further ahead, expectations are for Chile to move from being a deficit market to a surplus owing to the depletion of copper ore grades.

Elsewhere in Latin America, Brazilian prices were flat between December and mid-February at $130-135/tonne c.fr, before dipping $5/tonne on the low end to $125/tonne c.fr. Weak soybean prices impacted fertilizer markets, putting downward pressure on the processed phosphates market in Brazil. However demand for MAP is expected to ramp up from mid-March, which may encourage sulphuric acid consumption and support pricing.

Average acid prices into the US Gulf trended below prices elsewhere in the Americas through the latter part of 2018. Prices averaged $115/tonne c.fr in Q4 2018, while the year to date price in 2019 is at $123/tonne c.fr. Tight supply in the west of the US was reported in February due to reduced supply at Grupo Mexico's Hayden smelter in Arizona. Kennecott's Utah smelter turnaround is also reducing acid supply by around 45,000 short tons.

While sulphuric acid imports in 2018 to OCP in Morocco were strong – estimated by Argus at 1.6 million tonnes – a question mark remains over the outlook for the year ahead. Continued growth at the processed phosphates hub is driving sulphuric acid consumption and the expectation is that OCP will import a similar volume through the year to meet demand.

Sulphuric acid exports from China were a major industry consideration for 2018 as the market has traditionally been a net importer. Exports totalled over 1 million tonnes for the year and Morocco was the leading market. According to the International Copper Study Group (ICSG), China continues to expand its copper smelting capacity and this is expected to rise by 3% by 2021. We continue to forecast significant increases to China's smelter acid production capacity – likely leading to China remaining an exporter in the outlook.

Prices are a consideration owing to some producers' logistical costs of moving acid from plant to port. One smelter producer's logistical costs are estimated at $30/tonne for instance. We would expect producers to be hesitant to export at a negative netback, thus price sensitivity is expected for some producers depending on location.

Price indications

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

Cash equivalent	October	November	December	January	February
Sulphur, bulk ($/t)					
Adnoc monthly contract	170	173	155	127	108
China c.fr spot	190	176	153	117	133
Liquid sulphur ($/t)					
Tampa f.o.b. contract	140	140	140	109	109
NW Europe c.fr	138	138	150	133	130
Sulphuric acid ($/t)					
US Gulf spot	105	103	100	100	100

Source: various

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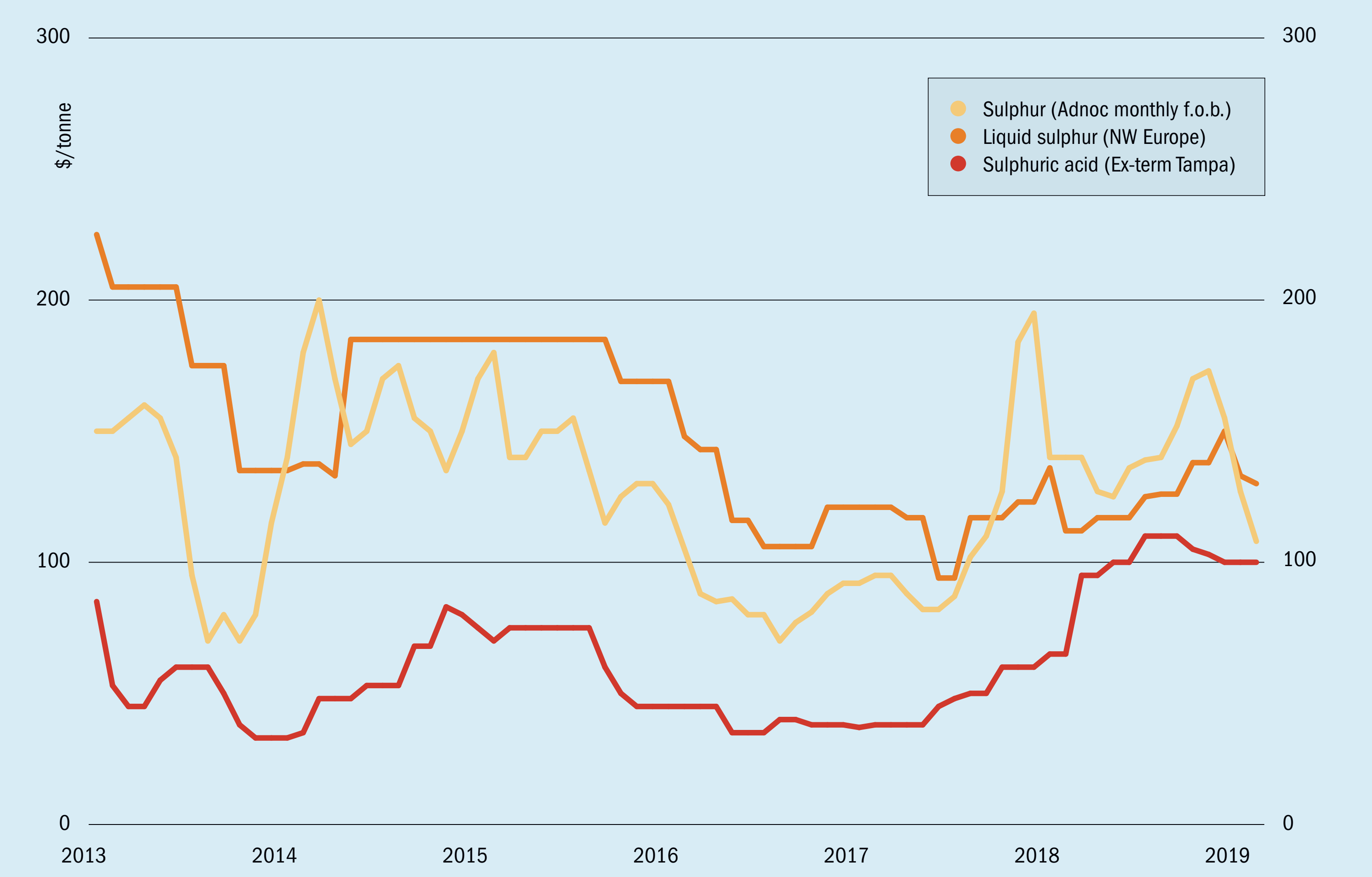
1 47 2 48 3 49 4 50 5 51 6 52 7 53 8 54 9 55 10 56 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46

Market outlook

Historical price trends $/tonne



Source: BCInsight

SULPHUR

- Upcoming deals for March will provide more clarity whether there will be a sustainable price recovery or if the upward trend is likely to be short-lived. Following tight supply in 2018, any supply shortages would provide support for an upside in pricing. Some projects are expected to see significant delays, such as the Barzan project in Qatar, keeping the market in balance for the short to medium term.
- The spring season will bring the reopening of the Volga Don waterway, and trade from the Black Sea may resume. This coupled with increased production capacity rates from the Kashagan project in Kazakhstan points to improved availability during 2019.
- Morocco and Brazil remain key import regions for sulphur due to the potential for growth from the downstream processed phosphates sectors.
- **Outlook:** Prices are expected to rebound if end users return to the spot market in key markets India and China. Middle East producer sentiment for March is stable to slightly firm – this may pave the way for the start of a price recovery. Increased availability from Central Asian suppliers may lead to putting a ceiling on price inflation. However, the tightness in the global acid market continues to support sulphur demand in the short term. Increased sulphur production in China will be a key marker to assess potential China imports as refineries are set to add significant new supply in 2019.

SULPHURIC ACID

- A firm restart date for Sterlite's Tuticorin smelter remains unclear. Once the smelter returns to production this will influence trade – with import demand set to ease. However, any delays to the timeline will be a supportive factor for acid pricing and imports to India.
- The turn of China to becoming a net exporter of sulphuric acid is a major market feature. Argus continues to forecast growth in China's smelter capacity and thus sulphuric acid production.
- The heavy turnaround schedule for the year ahead points to periods of tightness, supporting a floor to pricing should prices ease further in the coming weeks.
- The downwards trend in the elemental sulphur market may put pressure on regional pricing alongside softness in downstream markets.
- OCP/Morocco's sulphuric acid imports continue to be a major market focus due to the range of suppliers and volumes needed. China was the leading supplier for 2018, accounting for 21% of OCP's total supply at 360,000 tonnes. European acid declined meanwhile. Expectations are for 2019 to see a similar volumes imported to 2018 but the medium and long term view remains in question due to the uncertainty surrounding OCP's purchasing strategy.
- **Outlook:** Global acid prices may ease slightly but a floor is likely to be found should supply remain tight as turnarounds get underway. Pressure from downstream markets and elemental sulphur may prevail if import demand slows. Key markets Chile, Morocco and Brazil will continue to support the market with import trade and pricing.

Sulphur Industry News

CANADA

Wapiti sour gas plant commissioned

SemCAMS says that it has completed commissioning of its 200 million scf/d Wapiti Gas Plant near Grande Prairie in western Alberta, and that it has begun processing sour gas and sending sales gas to market. The plant began operations at the end of January, more than two months ahead of the original April 1st 2019 target date, and was also completed on budget, according to the company. At capacity, the plant will produce approximately 350 t/d of sulphur from hydrogen sulphide removed from the gas.

"The successful completion of this project on budget and ahead of schedule reflects the strength of SemCAMS' engineering and operations staff and the company's best-in-class ability to execute complex, large-scale projects in a safe, cost-efficient and timely manner," said Dave Gosse, president of SemCAMS ULC. "We look forward to continuing this trend on the other projects we are pursuing in our effort to provide Montney and Duvernay producers competitive and cost-effective midstream services."

Devon Energy to exit oil sands patch

US-based Devon Energy Corp. says that it is looking to sell off its Canadian assets, as well as its Barnett Shale holdings in Texas, during 2019. In a press release the company said that its US oil resource plays were "rapidly building momentum and achieving operating scale" and that the move would "accelerate value creation for our shareholders by further simplifying our resource-rich asset portfolio". Devon operates the Jackfish oil sands complex, which produces 105,000 bbl/d via steam assisted gravity drainage methods (SAGD). It had also been developing the 105,000 bbl/d Pike oil sands project in partnership with BP, which received regulatory approval in 2014, but which has not yet begun construction. It follows several other non-Canadian companies that have moved out of oil sands in the past few years, including Statoil, Total, ConocoPhillips and Murphy Oil.

Oil sands production represented two thirds of Canadian crude output in 2018, although pipeline capacity constraints, concerns over carbon intensity and lower oil prices continue to crimp future development.

Loan guarantee for upgrader project

The Alberta government is offering a C$440 million loan guarantee for a new C$2 billion oil sands upgrading facility. Alberta Premier Rachel Notley said that the guarantee would be provided for Calgary-based Value Creation Inc., which plans to build a 77,500 bbl/d partial upgrading facility near Edmonton. The facility would process bitumen into medium grade oil and reduce the need for oil sands companies to use expensive diluents like natural gas condensate to lighten their crude before shipping it to the US via pipeline. Value Creation says that it has the ultimate aim of scaling the upgrader in segments up to 500,000 bbl/d. A final investment decision on the first phase is expected by mid-2019

Other companies are looking at alternatives to using diluents to produce 'dilbit' – dilute bitumen – which can be up to 30% condensate by weight. MEG Energy Corp. is developing another partial upgrading technology which it calls HI-Q. This process removes and recycles diluent used in its initial processing, separating out the lighter and heavier portions of the bitumen, then removing solid materials known as asphaltenes. Cenovus Energy meanwhile is developing a 1,000 bbl/d partial processing pilot plant to reduce its diluent bill, and Husky Energy Inc. is working on a similar 500 bbl/d pilot plant for its diluent reduction technology at its Sunrise oil-sands project near Fort McMurray. Other alternatives include a technique being developed by CN Rail to convert the bitumen into solid briquettes which it calls CanaPux, for the briquettes' resemblance to ice hockey pucks. Heated bitumen is coated with a thin layer of shredded recyclable plastics and then shaped into the pucks. The plastic coating stops them from sticking together when stacked in rail cars, and is removed and recovered for reuse by heating at the other end. The company says that it hopes to start using CanaPux for transportation by the end of 2020.

Devon Energy's Jackfish 2 oil sands site.

UNITED KINGDOM

Breakthrough in sulphur polymer research

Researchers at the University of Liverpool say that they have found a way of catalysing the process of cross-linking sulphur chains with organic molecules – a process known as 'inverse vulcanisation'. In a paper published in *Nature Communications*, the researchers say that they found that the addition of a small amount of zinc diethyldithiocarbamate to the process reduces the required reaction temperatures and speeds reaction times. It also increases reaction yields, improves the physical properties of the polymers and prevents production of harmful by-products.

Dr Tom Hasell, leading the research group, said: "It makes inverse vulcanisation more widely applicable, efficient, ecofriendly and productive than the previous routes, not only broadening the fundamental chemistry itself, but also opening the door for the industrialisation and broad application of these fascinating new materials in many areas of chemical and material science."

The researchers suggest that being able to make useful plastics from sulphur could reduce our dependence on petroleum-based polymers, and make plastics easier to recycle. Sulphur polymers also potentially have applications outside traditional petrochemical plastics; while carbon polymers block infrared light, sulphur polymers are transparent to it, and might find use in thermal imaging lenses. They could also be used in batteries and water purification.

Conviction in Petrofac bribery case

David Lufkin, a former executive of UK-based oil firm Petrofac, has pleaded guilty at Westminster Magistrates' Court to 11 counts of bribery as part of an ongoing investigation by the UK Serious Fraud Office into Petrofac and its subsidiaries. The offences relate to offers made to influence the award of contracts to Petrofac worth up to $730 million in Iraq, and up to $3.5 billion in Saudi Arabia. Payments of approximately $2.2 million were made by Petrofac to secure a $329.3 million engineering, procurement and construction (EPC) contract on the Badra oilfield in Iraq, which was awarded to Petrofac in February 2012. Further payments of approximately $4 million were made by Petrofac for an operation and maintenance contract on the Fao Terminal project in Iraq, which was awarded to the company in August 2012. In Saudi Arabia, Petrofac made payments of approximately $45 million between July 2012 and November 2015, including $5.8 million for EPC contracts for the Petro Rabigh Petrochemical Expansion Project, and $21.4 million to secure EPC contracts for the Jazan Refinery and Terminal Project in December 2012. Another $19.5 million was paid for the award of an EPC contract for a sulphur recovery plant as part of the Fadhili Gas Plant Project in November 2015, worth approximately $1.56 billion.

In a press statement, Petrofac said that no charges had been brought against any Petrofac Group companies or employees, and that no current board member of Petrofac is alleged to have been involved. Petrofac chairman René Médori said: "the SFO has chosen to bring charges against a former employee of a subsidiary company. It has deliberately not chosen to charge any Group company or any other officer or employee. In the absence of any charge or credible evidence, Petrofac intends as a matter of policy to stand by its employees."

IRAN

Second offshore platform in place

The second platform of South Pars phases 22-24 has been installed at its designated offshore spot according to Iran's Pars Oil and Gas Company, which is in charge of developing the gas field. Platform 24A will produce 500 million scf/d of gas from the 2,300 tonne platform. Overall, phases 22-24 are expected to produce 56 million cubic metres per day (2 billion scf/d) of sour gas, as well as gas condensate, 2,900 t/d of LPG and 2,750 t/d of ethane. Onshore processing will recover 400 t/d of sulphur from the gas. Pars Oil and Gas announced in January that total output from the mega South Pars field has reached 600 million cubic metres per day, more than double

IOC's Bongaigaon refinery.

the amount of gas flowing five years ago. When all 28 of the South Pars phases are complete, projected to be some time this year, Iran's total gas production will reach 1 billion m^3/d.

INDIA

Sulphur recovery project to be operational by the end of the year

The Indian Oil Company says that its upgrade to its Bongaigaon refinery in Assam is due to be operational by the end of 2019. Speaking to local media, Deputy General Manager D. Nandi said that the refinery is being expanded to produce Bharat State VI (Euro-VI) quality diesel to meet Indian government deadlines for fuel quality improvements. The project involves expanding diesel hydrotreater capacity by 1.6 million t/a, as well as adding a naphtha hydrotreating unit, a new sulphur recovery unit and amine treatment unit.

Exports begin from Paradip

IOC says that exports have begun from its new 15 million t/a refinery at Paradip in the eastern state of Odisha, including naphtha, diesel, gasoline and aviation fuel. The company said that it expects to ramp up to full capacity during the 2019-20 financial year, which runs from April to April. The refinery can process 100% high sulphur and heavy crude to produce a variety of products, and has a total sulphur production capacity of 1,050 t/d. IOC says that the company is also considering a 10 million t/a expansion of the refinery, but would need to purchase additional land next to the existing site to do so.

UNITED ARAB EMIRATES

Another Ghasha contract award

The Abu Dhabi National Oil Company (Adnoc) has awarded a contract for dredging, land reclamation and marine construction to build 10 artificial islands and two causeways in the first phase of development of the Ghasha Concession. The contract, awarded to the UAE's National Marine Dredging Company (NMDC) is valued at 1.36 billion and will take 38 months to execute. The Ghasha Concession consists of the Hail, Ghasha, Dalma, Nasr and Mubarraz offshore sour gas fields, which are being developed as part of Adnoc's 2030 smart growth strategy. UAE Minister of State and Adnoc Group CEO, Dr Sultan Ahmad Al Jaber, said: "as one of the world's largest sour gas projects it will make a significant contribution to the UAE's objective to become gas self-sufficient and transition to a potential net gas exporter."

In February 2019 it was announced that Adnoc had received six EPC bids for the Dalma gas project, expected to be worth around $1 billion.

FEED contract awarded for new refinery

Adnoc has awarded the pre-front end engineering design (FEED) contract for its new 600,000 bbl/d refinery in Ruwais, as part of plans to create the world's biggest integrated production facility. British oilfield services firm Wood Group won contract, which is the second stage of a four-phase process to construct the facility, according to Adnoc. Design work is expected to be completed by the end of the year. The UAE is attempting to move downstream and capture more value from its oil reserves, boosting its refining capacity by more than 65% to 1.5 million bbl/d by 2025 and tripling domestic petrochemical production to 14.4 million t/a. The downstream investment is centred around Ruwais, the site of Adnoc's existing 920,000 bbl/d refinery. As well as the new refinery, Adnoc is also trying to develop Ruwais into a petrochemical hub, including new derivatives and conversion parks. Last month OMV and Eni took 15% and 20% stakes respectively in Adnoc Refining and jointly set up a trading unit which will handle 70% of Adnoc Refining's exports.

Occidental wins onshore sour gas concession

US oil firm Occidental Petroleum has won Abu Dhabi's first competitive onshore bidding round, taking a block next to the ultra-sour Shah field for a fee of $244 million. The company will hold a 100% stake in Onshore Block 3 in the exploration phase as part of its 35-year concession agreement. It is believed that the concession could hold as much as 3.5 billion barrels of oil and up to a trillion cubic feet (tcf) of sour gas, according to Occidental Petroleum. It is possible that the gas could be processed at the neighbouring Shah facilities, which are 40% owned by Occidental, and where capacity is being expanded to 1.3 billion cubic feet per day (bcf/d) from the current 1.0 bcf/d. Shah produces 3.5 million t/a of sulphur.

Sharjah gas exploration licensing round awards expected soon

While most of the exploration and production work in the UAE has focused on Abu Dhabi, the northern UAE emirate of Sharjah has also opened a licensing round for gas exploration and development. The emirate will award licenses under 30-year terms with a 10-year extension option. The exploration term is separated into three 2-year periods. Bids, based on drilling commitments, closed in late 2018 and winning bidders are expected to be announced this year. Companies selected to help develop Sharjah's fields will have access to existing gas and condensate infrastructure as well as SNOC's export terminals.

Like many countries in the region, Sharjah's power requirements are rapidly increasing, and gas production declines and power plant fuel shortages have contributed to electricity outages in the emirate over the past few years. Sharjah signed a memorandum of understanding with German company Uniper in 2016 to import LNG into Hamriyah port and supply gas to power plants operated by Sharjah Electricity and Water Authority (SEWA). It plans to install a floating storage and regasification unit at Hamriyah by 2020.

Abu Dhabi installs sulphur battery storage

The Emirate of Abu Dhabi has unveiled what it calls the world's largest 'virtual battery plant'. The sodium sulphur batteries have been installed at ten different locations but they are controlled by the Emirate's department of energy as a single unit. Altogether Abu Dhabi has installed 108 MW/648 MWh of electricity storage, for storing electricity generated by renewable solar energy for later use. In total it is five times the size of a comparable battery system installed in Australia in 2017. The UAE is making a major push towards using renewable energy as it targets 60% of its energy needs from renewable sources by 2050, and is projecting a spend of $160 billion by 2030 on renewable energy projects.

Sodium sulphur batteries were used for the energy storage units rather than more conventional lithium ion cells because it is said that they perform better at higher temperatures making them a lot more robust during the hot Arabian summers. The new battery system is of sufficient size that it could in theory provide up to six hours of backup power in case Abu Dhabi's electricity grid goes down. The batteries were manufactured by Japan's NGK. The company says that for such longer-duration storage, sodium-sulphur batteries become cheaper than lithium-ion batteries.

UNITED STATES

Exxon to expand Beaumont refinery

ExxonMobil has made a final decision to invest in the planned expansion of its Beaumont crude refinery in Texas. The company has begun construction of a new, third crude distillation unit within the existing site boundary to expand capacity by more than 65% or 250,000 barrels a day (bbl/d). Exxon says that the new unit will be on stream by 2022. It forms part of the company's previously announced plans to build and expand manufacturing facilities in the US Gulf region, which include establishing a new unit in Beaumont to increase production of ultra-low sulphur fuels, and building a new 1.5 million t/a ethane cracker at the company's Baytown site.

GERMANY

Refinery restarts for low bunker fuel production

HES International says that it will partially re-start its 260,000 bbl/d refinery at Wilhelmshaven in north Germany to produce around 40,000 bbl/d of low sulphur bunker fuel. The vacuum distillation unit (VDU) is to be operational before January 2020, when the new International Maritime Organisation rules on sulphur content of bunker fuel come into force, when a shortage of compliant fuel is expected. The refinery was idled in 2010 for economic reasons, although storage facilities at the site have remained in operation.

Sulphuric Acid News

INDIA

Setback for Vedanta as Supreme Court pushes case back to Tamil Nadu

Vedanta Resources, owner and operator of the Sterlite copper smelter in Tuticorin, has suffered a setback in its attempts to reverse a closure decision made by the Tamil Nadu Pollution Control Board (PCB) and government of Tamil Nadu state. The Indian Supreme Court set aside the National Green Tribunal's (NGT's) judgement reversing the closure order, and also revived a previous PCB closure order from 2013. While the court said it would not deal with the merits of the cases, it argued that from a legal standpoint the NGT did not have the judicial review powers to reverse the local rulings, and said that the appeal should in any event have been held in the Tamil Nadu high court in Chennai, and that Sterlite had in effect attempted to bypass the local court by bringing the case to the Supreme Court.

Tamil Nadu had ordered the smelter permanently closed in May 2018 following complaints by locals that they were being affected by sulphur dioxide from the smelter, around 6km outside Tuticorin. On March 23rd 2018 SO_2 emissions from the Sterlite sulphuric acid plant 1 chimney exceeded the permissible 477 parts per million (ppm) and for a period of 3 hours exceeded the maximum measurable amount of 1,123 ppm, according to data recorded at the PCB. The company claims to have been calibrating the pollution monitor at the time of the leak, and said that the readings should not be taken as a true representation of the actual emission during operation of the smelter. Local protests over the operation of the smelter led to riots in May 2018 in which the police opened fire, killing 14 protestors, and prompted the permanent closure order 6 days later.

Sterlite's CEO P Ramnath said the Supreme Court order was only based on legal jurisdiction and that the company remained "confident" that it would win in the Tamil Nadu high court on the case's merits. In the meantime, Vedanta reported a 21% fall in profits for 4Q 2018. The company's copper production was down by 77% to 23,000 tonnes because of the closure of the 1,200 t/d copper smelter. The lack of sulphuric acid from the smelter to feed phosphoric acid production in the region has led to a quadrupling of sulphuric acid prices in Tamil Nadu and a 20% increase in phosphoric acid process. ■

CANADA

Profits warning over Chile delays

SNC-Lavalin shares fell by 25% at the end of January after it issued a profit warning for its full year 2018 figures. The company said that core earnings from its mining unit could record a loss of up to C$350 million, related to troubles in Saudi Arabia and Chile. Tensions between Canada and Saudi Arabia worsened in August 2018 after a dispute over the arrest of human rights activists in Saudi Arabia, and the company said it would take a C$1.24 billion impairment charge to cover the financial impact on the company's oil and gas sector. The company also said it had a "serious problem" with a mining sector contract with an undisclosed client which suffered "substantially increased costs in Q4 2018", but this is widely believed to refer to Codelco in Chile. SNC-Lavalin won a contract from Codelco to help upgrade the Chuquicamata copper mine in Chile in 2012, followed by a deal to build sulphuric acid plants at the mine in 2016. Last year, however, the Chilean company faced mass protests at the mine as the planned overhaul faced delays and rising costs due to unexpected site conditions, environmental and safety measures, as well as underperformance from sub-contractors. SNC-Lavalin says that it aims to complete the project in the second quarter of 2019 as it had agreed to settle the dispute with the help of an independent third party.

The company is also facing a trial over corruption charges in Canada over its involvement in Libya between 2001 and 2011. In December CEO Neil Bruce said that reputational damage from the corruption charges had cost the company more than C$5 billion, and the company is looking for an out of court settlement.

POLAND

Grupa Azoty Police signs phosphate rock supply deal

Grupa Azoty Police says that it has signed a contract giving it access to low-cadmium phosphate rock deposits until 2021. The deal is a trilateral one between Grupa Azoty Police as the buyer, Ameropa AG as the seller, and Somiva SA as the producer, according to Grupa Azoty. Tightening EU regulations on cadmium content of phosphate fertilizers are likely to drive European producers to import more phosphate rock from Russia and the CIS, where there are extensive deposits of such rock, and less from Morocco, where the cadmium content of phosphate rock is higher. This deal actually covers rock from Senegal, where Somiva SA has held a 25 year mining license for deposits in the Matam region since 2011. First minerals from the deposit were delivered to customers in the third quarter of 2014. Since 2015, Somiva has been supplying phosphate rock to customers in Europe, Africa, the Middle East, and North and South America.

The contract, with a total value estimated at $64 million, runs to February 28th 2021. Wojciech Wardacki, President of the Grupa Azoty Police board, said: "Long-term access to low-cadmium phosphate rock is becoming a priority and a strategic decision for any manufacturer of fertilizers targeting the European market. This contract guarantees Grupa Azoty Police access to low-cadmium phosphate rock from a stable source of verified quality which ensures that EU requirements will be met now and in the future.

SAUDI ARABIA

Trafigura to build huge new smelter complex

Global commodities trader Trafigura says that it has reached agreement with a Saudi partner to build a giant copper, zinc and lead smelting complex in Saudi Arabia at an investment cost of $2.8 billion. The joint venture, SmeltCo, will be a 50-50 partnership between Trafigura and Modern Mining Holding, a subsidiary of the Riyadh-based Modern Industrial Investment Holding Group. The integrated smelter will be sited at Ras Al Khair Mineral City on the east coast of Saudi Arabia, which is also the site of Ma'aden's phosphate complex. On completion, the integrated smelter complex will have a production capacity of 400,000 t/a of copper, 200,000 t/a of zinc and 55,000 t/a of lead.

Modern Mining vice chairman and CEO Abdulaziz Fahad Al Hamwah said: “SmeltCo closes the gap in the kingdom’s ‘midstream’ mining value chain with the production of high-quality premium base metals. The project is aligned with Saudi Vision 2030 which calls for developing and capturing maximum value from the mining sector.”

Phosphate supply deal signed with Kribhco

The Saudi Arabian Mining Company (Ma’aden) has signed a $2 billion memorandum of understanding with Indian fertilizer producers Indian Potash Ltd (IPL) and the Krishak Bharati Cooperative (Kribhco). The memorandum was signed during the visit of Crown Prince Mohammad Bin Salman to India, and covers supply of 5 million t/a of diammonium phosphate (DAP), nitrophosphate (NP) and NPK fertilizers over the next five years. IPL will receive 3 million tonnes and Kribhco 2 million tonnes. In a press release, Ma’aden said that the memoranda are part of the company’s drive to strengthen its position with strategic partners to serve the Indian phosphate fertilizer market. The company said that it is also exploring “opportunities to enhance its cooperation in the Indian market; including CSR programs to encourage better use of fertilizers”.

INDONESIA

Work begins on HPAL plant

According to Chinese stainless steel giant Tsingshan and its project partners in the QMB New Energy materials project GEM, Brunp Recycling, PT Indonesia Morowali Industrial Park (IMIP) and Hanwa, piling work began in mid-January on the companies’ new $700 million high pressure acid leach (HPAL) nickel plant at Morowali on the island of Sulawesi. Tsingshan, already notorious as a disruptor of the nickel market with its investment in nickel pig iron (NPI) production, is now seeking to move into higher purity battery-grade nickel to capture some of the rapidly increasing market as electric vehicle production takes off around the world. However, most industry analysts have cast doubt on Tsingshan’s ambitious timescale for the project and the low cost estimates. A $700 million investment cost for a plant producing 50,000 t/a of nickel translates to just $14,000 per tonne of installed capacity – far lower than any actually operating HPAL plant. That, plus Tsingshan’s initial estimate that the plant could be operational by the end of 2019, and the long history of operating difficulties with other HPAL plants, have raised considerable scepticism. Tsingshan is already reportedly talking about 2020 as a start-up now, and 2021-22 may be a more realistic date. Nevertheless, there is a structural deficit in the nickel market at the moment, with prices on the rise and inventories – especially of ‘class 1’, battery grade nickel – falling.

At the moment there is no news on sulphuric acid production at the site, but comparable plants elsewhere require several hundred thousand tonnes per annum, depending on nickel ore grades.

CUBA

Sherritt reports higher nickel production at Moa

Sherritt reported in its 2018 full year results that production at its Moa Bay HPAL plant was up 4% in 4Q 2018, with Sherritt’s share

PHOTO: KATANGA MINING

Concentrator at Konkola Copper Mines, Zambia.

of production at 4,294 tonnes. Full year mixed (Co/Ni) sulphides production was up 2%, at 17,563 tonnes, in spite of a disruption in hydrogen sulphide supply in Q4. The company said that production growth was largely driven by the deployment of new mining equipment completed in Q3 2018 that resulted in improved ore access and reduced equipment downtime. Production at the Amabatovy joint venture HPAL plant was 6% down for the year on 2017 due to the effects of Cyclone Ava, but up 12% for the 4Q 2018 figure. Sherritt reduced its ownership in Ambatovy from 40% to 12% at the end of 2017.

ZAMBIA

ERG suspends copper and cobalt production

Production of copper and cobalt has been suspended at the 55,000 t/a Chambishi refinery in Zambia due to a constrained supply of feedstock. Like many other Zambian copper smelting complexes, Chambishi uses copper and cobalt concentrates imported across the border from the neighboring Democratic Republic of Congo, including from ERG's Boss and Frontier Mines. However, the imposition of a new 5% duty on copper concentrates has caused operators there to suspend production due to poor economics. In January, just days after the imposition of the new duty on January 1st, Konkola Copper Mines cut its operations at the Ngchanga copper smelter. The suspension could mean that feed of up to 13,750 tonnes per month of copper concentrates originally destined for Chambishi could have to be resold to other smelters, either for local consumption or in overseas markets.

The move highlights concerns in cobalt markets that the DRC is now responsible for 70% of the world's cobalt production, a metal increasingly in demand for electric vehicles, production of which is expected to quadruple over the next decade. Political instability, resource nationalism and corruption as well as logistical challenges in DRC are all becoming worries for cobalt users. Last year a new mining code imposed a series of taxes on western miners and Glencore was forced to write off $5.6 billion in debt to safeguard its joint venture with Gécamines, the DRC's state mining company, and its subsidiary Katanga Mining warned recently that it may not be able to sell any cobalt until 2020 because of a dispute with the DRC government. DRC's dominance over the cobalt market – mined and smelted at the same time as copper – is expected to rise to 75% this year as new Chinese mines and the Luxembourg-headquartered Eurasian Resources Group ramp up production. Low production costs mean that supply from outside DRC cannot compete, and the wave of new DRC production is encouraging this as increased supply leads to falling cobalt prices.

UNITED STATES

Concerns over potential breach in gypsum reservoir

Mosiac Fertilizer has been taking remedial action after concerns that one of its gypsum-walled wastewater reservoirs at St James Parish, Louisiana might breach. The wall of the reservoir, made from phosphogypsum left over from phosphate processing, was observed to have shifted, and measurements indicated movement in the clay layers beneath the wall. The company has drained 200 million gallons from the acidic waste water reservoir, and is working to shore up the reservoir wall. The company says that its modelling indicates that any breach would be at the top of the wall, and that the volume of water released would be containable within the company's site, not entering waterways outside the property such as the Mississippi River.

Copper leaching to begin in 4Q 2019

Excelsior Mining Corp. says that construction has started at the company's Gunnison Copper Project in southeast Arizona, and that it expects first copper production in the last quarter of 2019. The mining will use in situ recovery using acid leaching. Hydro Resources has begun drilling the production wellfield and accompanying compliance wells. There are currently three drilling rigs on site with two additional rigs arriving soon. A total of 63

PHOTO: EXCELSIOR MINING

Acid storage area construction at the Gunnison Copper Project.

wells, including 41 production wells and 22 compliance wells totalling approximately 82,000 ft. will be completed. The company says that the significant number of compliance wells will ensure groundwater protection as per state and federal regulatory requirements. Drilling of the production wellfield is expected to be finished in Q2 2019.

"Our ability to move quickly from the close of project financing to the initiation of construction at our Gunnison Copper Project is a demonstration of the operational capacity and experience of the Excelsior team," said Stephen Twyerould, president & CEO. "We look forward to updating all stakeholders as we move through the construction process. Our approach during this stage of development will remain, as always, focused on delivering technical excellence and long-term value for our shareholders."

Schmueser and Associates has been chosen as the general contractor. Construction activities include new acid storage facilities designed to enable the company to take advantage of market acid pricing opportunities as they arise.

DEMOCRATIC REPUBLIC OF CONGO

Acid plant commissioning set for 4Q 2019

In its 2018 annual results presentation, Katanga Mining said that it expected its new acid plant at the Kamoto Copper Company to be commissioned at the end of 2019. Katanga says that the plant is intended to improve the reliability of supply of sulphuric acid and sulphur dioxide to the whole ore leach project processing circuits. Detailed design work has been completed, civil works and earthworks are progressing and long lead time items are arriving at the site for assembly. The whole ore leach project is intended to produce 300,000 tonnes of copper cathode over the life of the mine by adding leach capacity at Luilu in order to leach oxide ores directly.

Smelter acid used to come from neighbouring Zambia, but the 5% Zambian import tax on copper concentrates from the DRC (see above) has caused several Zambian smelters to shut down, reducing acid availability for DRC leaching operations. Like Zambia, the DRC has also raised its taxes on copper production, in the case of the DRC on royalties, from 2.0 to 3.5%, with an additional 'super profits' tax when profits exceed by more than 25% forecasts from the mine's original feasibility study. The DRC government is gambling that its crucial role in the global cobalt market will be sufficient to keep copper operations going.

BRAZIL

Acid plant may be closed in restructuring plan

Brazilian fertilizer company Fertilizantes Heringer SA has decided to close several of its plants and distribution centres as part of a restructuring plan to lower its debt burden. The company has also filed for bankruptcy protection. In a message to shareholders, CEO Dalton Carlos Heringer said that the restructuring became necessary after some creditors obtained a favourable court decision allowing them to freeze bank accounts to guarantee debt repayment. Heringer was reported to be $800 million in debt at the end of 3Q 2018. The company has 16 NPK blending plants and other units, nine of which were to be idled as part of the restructuring plan. The fate of the company's sole sulphuric acid plant remains unclear at present.

People

Lucid Energy Group has hired **Brian T. Raber** as senior vice president and COO. Lucid CEO Mike Latchem said in a statement: "We are very pleased that Brian Raber has joined our team. He brings vast experience overseeing major capital projects. Brian's experience will be immediately accretive to Lucid and he will play a key role in the further development and expansion of our assets. His leadership skills and project management style will add significant value to Lucid as we execute our long-term strategic growth plans in the Delaware Basin."

Before joining Lucid, Raber served as senior vice president, engineering and project management for Summit Midstream Partners LLC. During his time at Summit, he implemented new procedures that resulted in on-time, on-budget project execution across seven active shale basins. He also played a key role in the expansion of Summit's footprint into the northern Delaware Basin, according to Lucid. Before that, he held senior management roles in operations and engineering at Century Midstream LLC, NiSource Midstream Services LLC, Hoover Energy Partners LP and Enterprise Products Partners LP. His experience spans greenfield systems design and construction, gas processing as well as sour gas treating and sequestration, and midstream operations.

Arianne Phosphate has announced the appointment of **Jean Fontaine** to the company's board of directors. Fontaine is the founder and president of JEFO Nutrition Inc., a producer of high-performance animal nutritional solutions. In conjunction with his appointment to the board, he has been granted 200,000 stock options at a price of $0.40 per share.

"Mr. Fontaine's appointment has come at a very significant time for Arianne," said Dominique Bouchard, Arianne Phosphate's Executive Chairman. "Mr. Fontaine has a proven record of growing business through innovation, entrepreneurship and global market penetration. These skills will be a strong addition to the board and overall direction of Arianne."

"I understand what it takes to build a successful international company," commented Fontaine. "I am fully aware of the challenges that smaller companies face and believe, from what I have seen, that Arianne has the ingredients in place to become a success story. I look forward to bringing my expertise to the board and working with management to influence this success. I also believe that my strong agricultural background and international network will help this happen."

EuroChem Group has appointed **Petter Ostbo** as its chief executive officer, effective from June 1st, 2019. Ostbo will take over from EuroChem CFO Kuzma Marchuk, who has been serving as acting CEO since September 2018. His previous employment was as executive vice president and chief financial officer of Yara International, before which he held the position of EVP Production at the same company, with responsibility for 28 production sites and four mines in 16 countries. He previously worked at McKinsey & Co from 2003-2010, and holds a Masters in Economics and Business Administration from the Norwegian School of Economics.

"The Board is delighted that Petter Ostbo is joining the team," EuroChem Group Chairman Alexander Landia said. "He is highly regarded in our industry and brings broad experience to the position. Petter's appointment demonstrates EuroChem's commitment to bringing in the best talent to take the company into the next chapter of its growth story. I would like to thank Kuzma for his continuing service as Acting CEO of EuroChem until Petter takes over."

"I am happy to be able to join EuroChem at this exciting time in the company's development," Mr Ostbo said. "The new potash and ammonia production present great opportunities for EuroChem, and I look forward to working with the Board and the management team to accelerate the next phase of growth."

Calendar 2019

MARCH

25-27
Phosphates 2019 Conference, ORLANDO, Florida, USA
Contact: CRU Events
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

25-28
Sulfuric Acid Round Table, ORLANDO, Florida, USA
Contact: Kathy Hayward, Sulfuric Acid Today
Email: kathy@h2so4today
Web: www.acidroundtable.com

APRIL

16-17
The Sulphur Institute (TSI) Sulphur World Symposium, PRAGUE, Czech Republic
Contact: Sarah Amirie, Director of Operations
Tel: +1 202 331 9586
Email: SAmirie@sulphurinstitute.org

28-2 MAY
Sour Oil and Gas Advanced Technologies (SOGAT) 2019, ABU DHABI, UAE
Contact: Nick Coles, Dome Exhibitions
Tel : +971 2 674 4040
Fax: +971 2 672 1217
Email: nick@domeexhibitions.com

JUNE

7-8
AIChE Clearwater Convention, CLEARWATER, Florida, USA
Contact: Ashley Rubright, AIChE Central Florida Section
Email: vicechair@aiche-cf.org
Web: www.aiche-cf.org

11-13
IFA 87th Annual Conference, MONTREAL, Quebec, Canada. Contact: IFA secretariat
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

JULY

15
Brimstone Amine Treating and SWS Course, HOUSTON, Texas, USA
Contact: Mike Anderson, Brimstone STS
Tel: +1 909 597 3249
Email: mike.anderson@brimstone-sts.com

SEPTEMBER

16-20
Brimstone Sulfur 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

NOVEMBER

4-7
CRU Sulphur 2019 Conference, HOUSTON, Texas, USA
Contact: CRU Events
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

The Gulf's growing sulphur surplus

The Arabian Gulf continues to be the fastest growing area for new sulphur supply. While large sour gas projects, some of them delayed from earlier years, continue to be the major source of new sulphur, large new refining projects in Kuwait and Saudi Arabia will also contribute to the growing surplus.

Over the next five years, annual global sulphur production is forecast to increase by about 9 million tonnes to reach about 73 million t/a in 2023, and it now looks as though up to two thirds of this supply growth will come from the Middle East. Monetisation of the region's abundant hydrocarbon supplies, via sour gas processing to provide sales gas for rapidly growing, energy-hungry cities and a continuing move downstream from oil production and export to refined product production are driving this increase. Saudi Arabia's rapidly expanding phosphate industry will absorb some of the new production, but overall the region's sulphur surplus seems set to continue its steady increase.

Abu Dhabi

The oil and gas rich Emirate of Abu Dhabi in the UAE has rapidly expanded its sulphur production over the past few years to become the largest sulphur producer in the world, with around 7 million t/a of sulphur capacity – more than 10% of global production – in 2018, as comparted to just 2 million t/a in 2013. This huge increase has mainly come from sour gas processing. Two huge processing plants – Habshan and Shah – take highly gas from across the Emirate and strip it of its significant H_2S content – an average of 23% at the Shah field.

The official resident population of Abu Dhabi is currently estimated at 1.45 million, and this is growing at 5% per year, but non-residents, especially guest workers from south and southeast Asia are believed to roughly double this to an estimated 2.9 million. The population has tripled in the past twenty years, and while the rate of growth is slowing, the authorities are still anticipating having to provide accommodation and power for at least a million more by 2030. The country's Economic Vision 2030 plan therefore continues to put the emphasis on developing domestic resources to meet these needs. While there has been a focus on developing solar power, via the Masdar City initiative and now most recently the huge 1.2 GW Sweihan photovoltaic power plant, which began operations in January this year, natural gas still provides 90% of Abu Dhabi's energy, and producing more natural gas is a key part of the Emirate's development plan. The UAE runs a net gas deficit, importing 18 bcm of gas per year along the Dolphin pipeline from Qatar.

Habshan processes gas from a number of fields, on and offshore, including the Bab development. Sales gas production is now 1.5 billion scf/d and sulphur production around 10,000 t/d (3.3 million t/a). Shah processes 1.0 billion scf/d of sales gas, but as the gas is sourer at Shah its sulphur production is actually 3.5 million t/a. Refining adds only another 100 t/d of sulphur to the mix, from the 800,000 bbl/d facility at Ruwais – capacity was doubled from 417,000 bbl/d in 2015. There are plans to expand the refinery with another 600,000 bbl/d of production, and Wood Group recently won the FEED contract for the work – the new refinery expansion is not expected to be on-stream before 2025, however.

The main prospects for expansion of sulphur production in Abu Dhabi come from the Shah field. Development work here is in the hands of Adnoc Sour Gas (formerly known as Al Hosn Gas), a 60-40 partnership between the Abu Dhabi National Oil Co (Adnoc) and Occidental Petroleum, which began operations in 2015. The company says that it plans to lift production from Shah to 1.5 billion scf/d of sales gas by 2022-23, which could see an additional 1.7 million t/a of sulphur production. A sulphur pipeline is being installed at the moment which will run 11 km from the processing plant to the sulphur granulation facility. Adnoc Sour Gas says that this will cater for future sulphur production expansion and increase flexibility around existing operations. The pipeline is scheduled to be commissioned in 2019. The company also recently installed a sulphur re-melt facility at Shah, in order to process the 2 t/d of sulphur that is 'lost' during normal transport and handling operations via conveyors to stockpiles or trains for onward transportation to the export terminal at Ruwais. Sand and rock contamination had previously meant that spilled sulphur had to be disposed of offsite. Now it will be recycled back into normal production.

In the meantime, Adnoc recently announced contract awards for new offshore sour gas projects, as part of the so-called Ghasha Concession, which covers a series of gas fields west of Abu Dhabi city, including the Hail, Ghasha, Dalma, Nasr and Mubarraz offshore sour gas fields. In February 2019 it was announced that Adnoc had received six EPC bids for the Dalma gas project, expected to be worth around $1 billion. Contracts were also recently awarded for the construction of 10 artificial islands and two causeways as the fields are in relatively shallow water (about 15 metres). Adnoc is being partnered in the development by Eni, which has a 25% stake, and Wintershall, with 10%. The ultimate aim is to produce collectively 1 billion scf/d of sales gas in the second half of the next decade in order to provide sufficient for electricity generation for another two million new homes, at an estimated cost of $20 billion.

Most recently, Adnoc has signed a sulphur supply deal with Morocco's OCP, running to 2025, with a steady increment in supply from Abu Dhabi to Morocco over that time. Morocco imported 2 million t/a of sulphur from Adnoc during 2016.

Bahrain

Bahrain's sulphur production comes from refining, at the Bahrain Petroleum Company (Bapco). Bapco's ageing refinery at Sitra is due for an expansion over the next few years. A consortium of TechnipFMC, Samsung and Tecnicas Reunidas has won the $4.2 billion EPC and commissioning contract to expand the refinery from 267,000 bbl/d to 360,000 bbl/d by 2022. With Bahrain's own oil reserves running down, the Bapco refinery is primarily supplied by pipeline from neighbouring Saudi Arabia. The pipeline's capacity was uprated from 230,000 bbl/d to 350,000 bb/d in October 2018 in advance of the expansion. A further 500 t/d of additional sulphur recovery capacity forms part of the refinery expansion, taking Bahrain from its current 150-160,000 t/a or so of production to double that at 320,000 t/a.

Iran

Iran produces sulphur from four refineries, at Tehran, Tabriz, Bandar Abbas, and Esfahan, as well as the Razi and Kharg petrochemical complexes, but as with many of the countries of the region, most of its sulphur production has come from natural gas processing. There are three sour gas processing complexes – at Khangiran (Hasheminajad) near Mashhad in the northeast of the country, at Ilam in the west near the Iraqi border, and at Assaluyeh, where the gas from South Pars is brought ashore, and Assaluyeh and Khangiran are the two largest of these.

Iran has been developing the South Pars field via a 28-phase development plan which has been ongoing for two decades, including gas production and associated onshore facilities, gas and condensate processing and downstream petrochemical works. Sanctions on Iran, especially US financial sanctions, have complicated the development of the field, and last year French major Total said that it was exiting the long-delayed $4.8 billion Phase 11 of the project, although by November Iran had persuaded the China National Petroleum Corporation (CNPC), which already had a 30% stake in the project, to also take Total's 50% share. Completion of Phase 11 may now not be until 2022-23. However, with the exception of this, the Pars Oil and Gas Company says that all other phases of the South Pars development plan will be complete by March 2020.

There is also another major offshore gas development programme underway at Kish, where production is due eventually to reach 5 billion scf/d of gas in five phases each of 1 billion scf/d. Phase 1 is under construction and Phases 2 and 3 under development. H_2S content is much lower there than at Shah, at between 70 and 200 ppm, but there is an onshore gas sweetening plant planned as part of the development.

Iran is also progressively revamping its ageing oil refineries – the country has suffered from a chronic shortage of refining capacity and has actually often had to resort to importing gasoline even while it was exporting oil. A basic overhaul of the 250,000 bbl/d Imam Khomeini refinery has been completed, as has modernisation work at Arak. The Isfahan refinery in central Iran is adding another 120,000 b/d to its capacity to reach 490,000 bbl/d, and Persian Gulf Star has started the third phase of its gasoline production operations, boosting capacity to 360,000 bbl/d by March 2019. Work is ongoing to improve sulphur recovery and lower sulphur fuel content to 10 ppm, with concomitant boosts to sulphur production. Iranian sulphur production is currently around 2 million t/a, but could rise by another 600,000 t/a, mostly due to the completion of the South Pars project. At the moment Iran is exporting about 1 million t/a of sulphur, mostly to China. However, during 2018 the US pulled out of the joint accord on the Iranian nuclear programme and reimposed sanctions, and the threat of further potential disruption could affect all of the oil and gas development projects.

Kuwait

Kuwait's sulphur production runs at about 800,000 t/a, with refining providing most of this. Kuwait has had ambitious plans to increase its oil and gas production for many years, but laws preventing foreign ownership of oil facilities and bureaucratic delays have pushed most of these projects back. The consequence has been a growing shortfall in natural gas to meet local demand, and as of last year Kuwait has become an LNG importer via a new terminal at Az Zour. To try and boost domestic gas production, the Kuwait Oil Co has launched a new Upstream Strategic Objective 2030 which aims to maximise production from existing associated gas fields, as well as tapping into sour, non-associated gas fields, especially in the northern, Jurassic formation. Kuwait aims to be producing 2 billion scf/d of non-associated (mostly sour) gas in 2040.

The first phase of the Jurassic development involves three processing facilities with a total capacity of 500 million scf/d of sales gas and 200,000 bbl/d of oil. The first of the three facilities was inaugurated at Sabriya in early 2018. This is planned to increase to 1 billion scf/d and 275,000 bbl/d when the fourth and fifth processing plants are completed in 2022-23. Sulphur output is expected to be 1,200 t/d at capacity.

More new sulphur production from Kuwait is projected to come from the expansion of refining capacity in the country via the Clean Fuels Project, which involves the upgrade and integration of the Mina Abdulla (MAB) and Mina Al Ahmadi (MAA) refineries, increasing the combined capacity of the refineries from 736,000 bbl/d to 800,000 bbl/d, and lowering the sulphur content of petroleum products – from 500 ppm sulphur to 10 ppm for gasoline and diesel and from 4.5% sulphur to 1% sulphur for bunker fuels. There is also a new 615,000 bbl/d refinery being built at Az Zour, which will replace the Shuaiba Refinery. The Clean Fuels Project is now looking at mid-2019 for completion.

Kuwait is looking at a significant increase to its sulphur capacity from all of these activites, and has been upgrading its sulphur handing capability. At Mina al-Ahmadi Kuwait National Petroleum Company (KNPC) has installed four storage tanks for liquid sulphur, with a total capacity of 18,000 tonnes, as well as 5,000 t/d of granulation facilities and a warehouse with a capacity of 145,000 tonnes of solid sulphur, together with a jetty for loading and export of the sulphur – to handle liquid sulphur from the KNPC Clean Fuels Project and facilities of the Kuwait Oil Co. Az Zour when it comes on-stream in mid-2019, will also have 5,000 t/d of sulphur forming capacity. In January this year Kuwait Petroleum moved to quoting a monthly sulphur price as a result of these capacity increases.

Table 1: **New sulphur capacity in the Middle East, 2018-2023, million t/a**

Country	Refining	Sour gas	Total
Abu Dhabi	0	1.7	1.7
Bahrain	0.15	0	0.15
Iran	0.1	0.55	0.65
Kuwait	1.65	0.4	2.05
Qatar	0	0.75	0.75
Saudi Arabia	0.5	1.7	2.2
Total	2.4	5.1	7.5

Source: BCInsight

Qatar

Qatar mainly processes slightly sour (ca 1% H_2S) gas from the huge offshore North Field to feed the massive LNG and GTL complex at Ras Laffan, on the northern tip of the Qatar peninsula. Sulphur recovered from these facilities is sent to the Common Sulphur Facility where it is formed and exported. Total sulphur recovery and forming capacity at Ras Laffan is approximately 3.5 million t/a, with actual production running at just over 2 million t/a, representing most of Qatar's 2.3 million t/a of production. The remainder comes from refineries and ethylene processing.

During the 1990s and early 2000s, Qatar rapidly expanded its petrochemical industries, and especially the production and export of liquefied natural gas (LNG). By 2009, the tiny country had become the world's largest LNG exporter, via two state-owned companies, RasGas and QatarGas (merged in 2018 to become Qatargas), based at the huge Ras Laffan site, and that year it exported 51 bcm of LNG, as well as another 17 bcm by pipeline to the UAE. Qatar actually had a moratorium on new gas development projects which ran from 2012-2017 and during this time it started to lose market share to other competitors, especially the US and Australia, both of whom are rapidly expanding their LNG export operations. Nevertheless, Qatar still represents almost 30% of the LNG market, and exported 82 million tonnes of LNG in 2017.

The only gas development project which proceeded during the moratorium was the Barzan LNG project, which actually dates back to 2007, with Qatar Petroleum in partnership with ExxonMobil. Contracting on the first phase, two LNG trains producing 1.7 bcf (48 mcm) per day, was delayed until 2010, when Japan's JGC won the $1.7 billion EPC contract for the onshore facilities, and Hyundai the $800 million EPC package for offshore work, including three wellhead platforms and two wet gas pipelines running around 70 km to the coast, as well as onshore pipelines delivering the gas to the processing plant. Costs escalated, however and work slowed. In 2016 gas leaks from one of the sub-sea pipeline meant that new pipelines would need to be laid – a similar issue to the Kashagan project in Kazakhstan. Qatar Petroleum now admits that commissioning is not likely before 2020.

Qatar is also looking towards other new LNG projects now that the moratorium is over, but a spat with Saudi Arabia and the other Gulf Cooperation Council countries over alleged support for terrorism (the Muslim Brotherhood) and Qatar's intervention in regional conflicts in Libya, Syria and elsewhere led to a Saudi-led embargo on Qatar from June 2017, and Qatar's recent withdrawal from OPEC. This in turn led to international oil and gas companies who wanted to work with Qatar having to compartmentalise their operations and move some of them to Doha, delaying contracts and raising costs. Nevertheless, Qatar is now looking to raise LNG exports to 110 million t/a by 2024 with four new LNG trains, each of 8 million t/a. Chiyoda is performing FEED work on the associated North Field Development Project to provide gas for the LNG facilities.

The new gas processing will of course produce new sulphur. Barzan, once it finally comes on-stream, will boost sulphur output by an estimated 700-800,000 t/a. The other new LNG trains will take output to well over 4 million t/a – sulphur handling capacity at the Common Sulphur Facility was expanded to 4.3 million t/a in 2018. Last year also saw Qatar move responsibility for sales and marketing of its sulphur to the Qatar Chemical and Petrochemical Marketing and Distribution Company (Muntajat), which now forms a unified marketing arm for Qatar Petroleum of all of its products, from urea to polymers and steels.

Saudi Arabia

Saudi Arabia is also looking to increased electricity generation for its young and rapidly growing population. Solar and nuclear form part of the mix – there is a target of 9 GW of solar electricity by 2023 and 17 GW of nuclear power by 2032, but it is recognised that natural gas will need to form a major part of the mix, as Saudi Arabia phases out generating electricity from burning oil, oil which it would rather export or process. Until a few years ago virtually all Saudi natural gas was gathered from oil production wells. However, this tied gas production to OPEC oil production quotas and left no room for expansion. Therefore, as with Abu Dhabi and Kuwait, Saudi Arabia is looking to expand its non-associated gas production in order to provide more gas to generate electricity. Currently the kingdom is targeting a 65% increase in gas production over the next decade. While Saudi Arabia has become interested in the possibilities of shale gas production and committed $10 billion to identifying and developing shale gas resources, this programme is still in its infancy, and so, as with Abu Dhabi and Kuwait, for the moment – aside from some smaller sweet gas plants like Midyan – producing more non-associated gas means processing more sour gas. A major programme of sour gas development is under way, with additional gas output from both onshore and offshore sour gas fields and several gas processing plants which are generating additional tonnages of sulphur.

The Wasit sour gas processing plant started up in 2016, with a gas processing capacity of 2.5 billion scf/d and sulphur production of 1,200 t/d, joining the earlier Kursaniyah plant which became operational in 2012. Gas for these facilities comes from the offshore Karan, Arabiyah and Hasbah sour fields. The next new gas plant will be Fadhili, which will take 2.5 billion scf/d of sour gas from an expansion of the Arabiyah-Hasbah fields. It is due to become operational at the end of 2019. Sulphur production at capacity is expected to be 4,000 t/d (1.3 million t/a). Other existing gas plants such as Berri and Hawiyah are being expanded to handle additional associated sour gas from oil production as well as some from non-associated fields.

In addition to these, Saudi Arabia is also looking to capture more value from its oil by expanding its downstream refining. The largest component of this is the new 400,000 bbl/d Jazan refinery, part of an integrated petrochemical complex, which is due to come into production towards the end of 2019. Sulphur output at Jazan is expected to be 400,000 t/a at capacity.

On the demand side, the only significant increase in regional demand is likely to come from phosphate processing in Saudi Arabia, at the Wa'ad al Shamal project, with capacity ramping up to a final requirement of 1.5 million t/a of sulphur. Another, third expansion to the Ras al Khair phosphate processing complex is now under development, with the ammonia plant contract awarded to Daelim in October 2018. 'Phosphate 3' will be of similar size to the previous two expansions and is looking at start-up in 2022.

Regional sulphur balance

Table 1 shows the total new sulphur capacity that is projected out to 2023. As always, projects are subject to delay, and ramp up to full production, especially for sour gas projects, can take a couple of years. But assuming that all goes to plan, this means a total of 7.5 million t/a of additional sulphur production in the region over the next five years. Saudi phosphate processing could perhaps absorb 2 million t/a of this, depending on the speed of commissioning of the Phosphate 3 project, but that still leaves a potential 5 million t/a of additional sulphur that could come to the market from the Arabian Gulf by 2023.

Selling and marketing this sulphur will be a challenge – Abu Dhabi's Adnoc has already formed a long-term relationship with Morocco's phosphate giant OCP, aiming to not only supply large additional volumes of sulphur into OCP's growing site at Jorf Lasfar, but also to help develop new markets in Africa. Recent developments in Kuwait and Qatar with the consolidation of sulphur marketing into larger organisations and development of forming capacity indicates that producers there are also looking towards a future where major additional sulphur volumes are available.

Sulphur as a fertilizer

Oilseed rape – a major consumer of sulphur nutrient.

The importance of sulphur in plant nutrition is becoming increasingly recognised. While many traditional sulphate-based fertilizers are still the major source of plant nutrient sulphur, a wide variety of new sulphur enhanced fertilizers are now available to help correct growing sulphur soil deficiencies.

Sulphur's important role in crop nutrition is not a new story. However, it is one that was largely obscured by other factors until the later years of the 20th century. At that time, developments in improving air quality and greater availability of new types of fertilizer conspired to reduce the amount of sulphur that was being deposited in the soil. As a result, the need to supplement 'naturally' occurring sulphur is becoming a progressively more urgent one worldwide.

The first key development in this was the recognition of the damage that sulphur dioxide in the atmosphere could do – first of all to plant and animal life via so-called 'acid rain', and then more recently to human health. The result was firstly a concentration on removing sulphur dioxide emissions from coal-burning power plants, via stack gas scrubbing, and then a progressive reduction in the sulphur content of vehicle fuels and stricter limits on emissions of sulphur dioxide from industrial processes, especially metal smelting. This has not only dramatically increased the amount of sulphur and sulphuric acid being produced by refineries, sour gas plants and smelters, but also removed that sulphur from the air, where some of it would eventually be carried to ground as soluble sulphates, providing 'free' sulphur fertilization.

The second key trend has been the switch away from older, more traditional fertilizers such as single superphosphate and ammonium sulphate towards other, higher analysis sources of phosphate and nitrogen, such as diammonium phosphate or urea, and in the potassium world a switch from potassium sulphate (sulphate of potash or SoP) towards potassium chloride (muriate of potash or MoP). Figure 1 shows this development graphically.

Sulphur in soil

Reduction in soil sulphur levels not only leads to visible sulphur deficiencies, which can be easy to spot, but more subtly to lower yields because sulphur is a key enabler of plant nitrogen uptake. During the 1900s and 2000s, The Sulphur Institute conducted extensive research and field trials in cooperation with the Chinese Ministry of Agriculture and various research institutes in China, and in India with the Fertiliser Association of India and International Fertilizer Industry Association (IFA) on the response of crops to additional sulphur nutrient which showed the extent of sulphur deficiency in Asian soils, and the improved response to adding sulphur to the fertilizer mix.

Sulphur can easily be added as elemental sulphur to mixes of NPKs, or even sown on its own. However, plants cannot take up sulphur in its elemental form. Instead they depend on thiobacteria to break the elemental sulphur down into soluble sulphate form, in much the same way that plants require urea to be oxidised to a nitrate before they can use it as a nutrient. The difference is that urea breaks down fairly quickly, but the conversion of sulphur to sulphate can be a protracted process, and sulphur spread during one growing season may not be available until the next.

There are two ways of countering this – the first is to spread the sulphur as sulphate. Numerous sulphate fertilizers are available, including ammonium sulphate, potassium sulphate, calcium sulphate (gypsum), as well as water soluble thiosulphates, more on which later. The issue with sulphates is that they are 90% available within only days of sowing to the plants, and so application must be carefully timed so that the sulphate is not carried away by rain before the plants are able to use it.

The other is to speed up the breakdown of sulphur to sulphate by increasing the surface area of the sulphur. One technique is to mix the sulphur with a 5% addition of bentonite clay. When in the ground, the clay absorbs water and expands, causing the brittle sulphur granules to break up into smaller particles which oxidise more rapidly to sulphate. The other is to mix the sulphur into a fertilizer in a smaller particle form, often smaller than 150 micrometers in diameter. This micronised sulphur is then more rapidly converted to sulphate. This is not quite as simple as it sounds, as elemental sulphur does not, for example, form a stable emulsion in urea, and so, for example in Shell's *Thiogro* technology, the sulphur is stabilised with a proprietary *ThioAdd* additive to give it an even dispersion in the urea.

Some of the major developments in the past decade in sulphur fertilization have involved greater control over sulphur particle size and dispersion in conventional fertilizers, leading to a growing range of 'sulphur enhanced' fertilizers.

Traditional sulphur fertilizers

Traditional sulphur containing fertilizers have been based around sulphates. The first commercial mineral fertilizer was single superphosphate (SSP), made from the 1840s onwards by the action of sulphuric acid on phosphate rock to produce a mixture of calcium phosphate and gypsum. The phosphate content of SSP is around 7-9% P (16-20% P_2O_5 equivalent), but it also has a sulphur content of 11-12%, as sulphate. SSP was joined in the late 19th century by ammonium sulphate $(NH_4)_2SO_4$, initially made from ammonia from coke oven gas reacted with sulphuric acid, and later as a by-product from other processes such as caprolactam manufacture, or

Fig. 1: **Use of higher-analysis fertilizers (blue) versus sulphur-containing products (red)**

Source: IFA

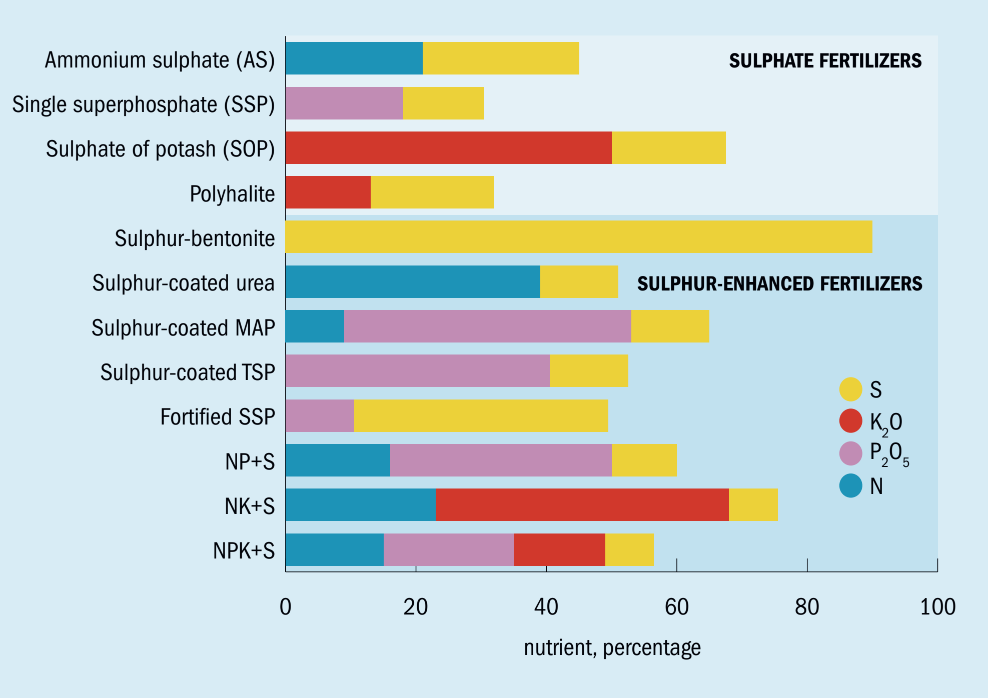
produced on purpose by the reaction of synthetic ammonia directly with sulphuric acid. Ammonium sulphate has a nitrogen content of 21%, and a sulphur content of 24%. In the early years of the 20th century, these were the most popular phosphate and nitrogen fertilizers respectively, and hence, as discussed previously, added many tonnes of free sulphur to the soil in addition to the desired P and N.

While as Figure 1 shows, the popularity of these fertilizers has been superseded by DAP and urea, they nevertheless still make up about 80% of all sulphur nutrient content of fertilizers applied to soil. Ammonium sulphate has actually seen something of a rise in popularity because of its widespread availability in China as a by-product of caprolactam manufacture for nylon fibres, and because of a growing awareness of sulphur deficiency in soils. Ammonium sulphate production reached 26.8 million t/a in 2017, according to IFA figures (5.6 million tonnes N, 6.4 million tonnes S). One third of this production was in China, 19% in the EU, and 15% in North America. Use was more widespread, with Asia the dominant consumer – as well as China, Indonesia, Vietnam, the USA, Brazil, Turkey and Mexico were all major consumers of ammonium sulphate fertilizer. Consumption is forecast to grow slowly to 27.7 million t/a by 2025.

World demand for single superphosphate (SSP) is just over 33 million tonnes (5.4 million tonnes P_2O_5, 4.0 million tonnes S), making it the second best selling fertilizer worldwide for both P and S content. Consumption is concentrated in four main markets, China, Brazil, India and Australia, which collectively account for 85% of total global demand. Because of its relatively low phospate nutrient content compared to diammonium phosphate (16-20% compared to 46%), it tends to be consumed in the country of origin, and export volumes have declined due to increasing competition from more economic high-analysis phosphates.

Finally, posassium sulphate/sulphate of potash (SoP) has always by contrast been something more of a niche product compared to the much more widely used potassium chloride (muriate of potash/MoP), but SoP is valued as a chloride-free source of potash for cash crops such as tobacco, tree nuts and citrus fruits. World demand is around 6.1 million tonnes currently (1.1 million tonnes S). China accounts for 55% of world consumption and has been responsible for much of the 2.1 million tonne expansion in SOP demand globally since 2007, while demand in other regions has remained relatively flat. Nevertheless, North America and Europe are also sizable markets, with around 25% of global demand between them.

Fig. 2: **Nutrient content of selected sulphate and sulphur-enhanced fertilizers**



Source: Fertilizer International

Sulphur-enhanced fertilizers

With a growing recognition of the issue of sulphur deficiencies in soils has come a rapidly proliferating range of sulphur containing or enhanced fertilizers (Figure 2). These typically use innovative technologies to incorporate elemental sulphur into higher analysis fertilizers, either within granules or as an external coating. Introducing a liquid sulphur spray to Urea, TSP, MAP or DAP during drum or pan granulation, for example, results in N and P products with a 5-20% elemental sulphur content. Sulphur-enhanced fertilizers combine nutrient availability with high use-efficiency, and also have good storage and handling properties. The market for sulphur-enhanced NP+S products has developed over the past decade, with particular take-up in the US, Brazil, India and parts of Africa.

Controlled release fertilizers (CRFs) can be produced by coating highly soluble nutrients such as urea with relatively insoluble coatings. While India uses the plant fibre neem, other polymers can be used, and elemental sulphur is also used as a coating – the sulphur breaks down slowly, eventually allowing the encapsulated to become available over a longer time period. Sulphur-coated urea (SCU) combines 77-82% urea (36-38% N) with a 14-20% sulphur coating. SCU is used for multiple nitrogen applications on sandy soils under high rainfall or irrigation conditions. It is marketed as a controlled release fertilizer for grass forage, turf, sugarcane, pineapple, cranberries, strawberries and intermittently-flooded rice.

IFA estimated the market for sulphur-coated urea to be 900,000 t/a (tonnes product) in 2016, with almost all of this market (ca 95%) in east Asia. There are issues with sulphur-coated urea as a controlled release fertilizer relating to the integrity of the sulphur coating of the granule. In transit, granules knock together and the relatively brittle sulphur coating can become damaged. Once the urea core of the granule is exposed to the elements, the controlled release aspect of it becomes ineffective. For this reason SCU has a low ability to be shipped long distances and is more often used close to its point of origin. This can be ameliorated with the use of a polymer coating along with the sulphur, producing polymer sulphur coated urea (PCSU), which is gradually taking over from ordinary SCU.

Recent developments

The last decade has seen the emergence of various speciality NP+S products. In North America, Mosaic has been selling its *MicroEssentials* range of fertilizers since 2008, containing 10-15% sulphur in a 50-50 mixed form of both sulphate (for initial availability) and micronized elemental sulphur to keep plants growing throughout the season. Sales of *MicroEssentials* topped 1 million t/a in 2013, with Mosaic reckoning 11% of US farmland now used them in one form or another.

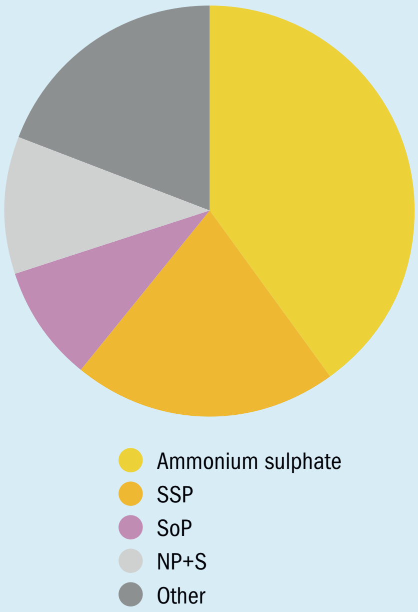
In Europe, Yara International offers two ammonium nitrate/calcium sulphate fertilizers to growers, with 9 and 13% sulphur respectively, while sulphur-containing products make up seven of the eleven fertilizers manufactured by CF in the UK, with up to 30% sulphur content. Russia's PhosAgro increased started up a 100,000 t/a production line at its Metachem site in 2015 sulphur-containing phosphate-potash fertilizers specifically formulated for priority markets such as Brazil. In December 2018, EuroChem began production at Russia's first 600 t/d urea ammonium sulphate (UAS) facility at Novomoskovsky Azot, 200km south of Msocow. Built in partnership with urea technology developer Stamicarbon, the facility will complement EuroChem's current portfolio of sulphur-enriched fertilizers, which includes ammonium sulphate (AS) and ammonium sulphate-nitrate (ASN).

In the Middle East, Abu Dhabi Fertilizers has the capacity to produce 24,000 t/a of sulphur-coated urea (SCU). Other SCU suppliers include Nutrien, ICL, Syngenta, Yara, Haifa Chemicals, Koch and JR Simplot. Qatar Fertilizers have been trialling a sulphur enhanced urea granulation system.

On the sulphur bentonite side, the major developer has been Tiger-Sul Products, a Canadian subsidiary of Connecticut-based HJ Baker & Bro, Inc. As well as its 90% sulphur bentonite product, Tiger-Sul also has a range of micronutrient enhanced sulphur bentonites with zinc, manganese, copper and iron, and *Tiger 50CR*, a 40-60 mix of sulphur bentonite and ammonium sulphate for 50% sulphur content with – as with Mosaic's *MicroEssentials*, a mix of sulphur and sulphate for longer term plant nutrient availability. The company began manufacturing in China and Canada in 2014.

The popularity of liquid fertilizers in North America, especially liquid ammonia and urea ammonium nitrate solution (UAN) has led to the use of soluble thiosulphates to produce sulphur enhanced liquid fertilizers. Tessenderlo Kerley, a leader in speciality liquid fertilizers, has four main thiosulphate products, with ammonium, potassium, calcium or magnesium, with a sulphur content of 10-26% sulphur.

Fig. 3: **Sulphur fertilizer consumption by type, 2017**



Total: 13.3 million tonnes S

Source: IFA

Shell Sulphur Solutions has developed its own micronised sulphur product, *Thiogro*, and has begun licensing it to key producers around the world, including a collaboration with SinoChem in China beginning in 2012. Sulphur enhanced phosphate lines have been licensed and installed at fertilizer plants in Asia, North America and Australia. A major licensing deal was concluded with OCP in Morocco in 2016.

A more recent breakthrough was the development of a dispersion of micronized sulphur in urea, called Urea-ES (Enhanced Sulphur). Shell worked with Sandvik Process Systems (now IPCO) and Uhde Fertilizer Technologies to develop Urea-ES *Rotoform* pastilles and *Urea-ES* granules, respectively, and now in conjunction with these companies is licensing the forming technology worldwide. Last year saw licensing deals for Urea-ES signed with H-Sulphur Corp in Korea to produce a 75% sulphur product, and with Two Rivers Terminal in the US Pacific Northwest, again for a 75% sulphur product, effectively using the urea to replace bentonite in a sulphur bentonite product.

Polyhalite

Israel Chemicals Ltd operates the world's only polyhalite mine, at Boulby in northern England. Polyhalite is a mixed sulphate mineral, with sulphates of potassium, calcium and magnesium. It is 48% sulphur by weight, but only 14% potassium. ICL markets a modified version which has had potassium added to it, with 37% potassium and 24% sulphur, as *Potashplus*. *Potashplus* is claimed to give a slower release of sulphur than competitive products, with 90% of sulphur being available in 13 days compared with ammonium sulphate where 90% availability is reached in three days. The Boulby mine has been operational since 2010. A neighbouring deposit of polyhalite is also under development by UK-based Sirius Minerals, with the company aiming to begin mining next decade.

Slow but steady growth

In 2017, IFA conducted a survey of sulphur nutrient use, covering 25 sulphur containing fertilizer products. This survey put world sulphur nutrient consumption in 2015 as 13.3 million tonnes S, higher than the 10-11 million tS/a that had been estimated at the time. However, the Sulphur Institute puts global requirement for sulphur fertilizer at closer to 24 million tonnes S over the next couple of years. This mismatch is the increasing sulphur deficiency in soils that needs to be tackled in order to achieve the kind of crop yields that the world will need in order to sustain a growing population.

Overall fertilizer demand is slowing in most markets as they mature. The rise in nitrogen consumption over the next few years is expected to be only around 1.1% per year, and in phosphate consumption only 1.6% per year. For sulphur fertilizer the comparable increase is expected to be 2.6% per year over the period 2018-2024, with Asia the largest source of new demand as sulphur deficiency is increasingly recognised and tackled. It is unlikely that traditional sulphur fertilizers such as AS, SSP and SoP will fill this increase. Rather, it is likely to be increasing use of sulphur enhanced versions of high analysis fertilizers like DAP and urea that capture most of this market share.

Projecting forward from the estimated 13.3 million tonnes S used in 2015, this would equate to approximately an extra 2.2 million tonnes of sulphur demand for sulphur fertilizers over the next five years.

Sulphur dust suppression in extremely cold temperatures

Dr Jeff Cooke, Director of Technology, and **Tibor Horvath**, Laboratory Manager for the IPAC Chemicals Division of DuBois Chemicals Canada discuss the use of dust suppressant chemicals on formed sulphur in freezing conditions when traditional water-based sprays are unusable.

All over the world, countries are continuing to recognise the importance of monitoring and reducing the impact that industrial processes have on the natural surroundings, local populations, and the workers that the particular industries employ. Regulations are becoming increasingly more stringent, and public awareness is acute as news of spills, releases, fires or worker injuries can spread rapidly through email and social media, and provide a far greater impact than traditional reporting in news media. Therefore there has been a renewed focus on incorporating safe processes and implementing practices that will enhance the safety of workers and minimise environmental consequences. This is particularly true in the energy sector, where sulphur compounds are removed from oil and natural gas and converted to elemental sulphur which, as a saleable commodity is necessarily handled during storage and transport.

Elemental sulphur is relatively benign from a toxicity standpoint; however, when transporting or storing solid sulphur in prill, pastille, lump or crushed bulk form, explosions and fires are certainly significant risks. Solid sulphur in storage piles or being transported in rail cars can easily be ignited by electrical means, embers, sparks, or other sources of ignition. Also, during the handling of granulated sulphur one is continually faced with the potential of dust generation. Without proper treatment using appropriate dust suppressants, equipment and precautions, dust generation can cause health (air quality) issues, pollution/contamination issues, loss of product, and perhaps most importantly create a serious fire and explosion hazard.

Sulphur is a flammable solid, and dust can rapidly accumulate in air during conveyor transfer, stacking/reclaiming and loading/unloading operations where the sulphur is subjected to turbulent air flow causing entrained fine dust particles to become airborne, along with new fines created through attrition caused by handling. Sulphur dust can also accumulate on infrastructure, particularly in indoor storage buildings. Sudden disturbance of this dust can cause locally high airborne levels exceeding the lower explosive limit of about 35 g/m^3; a very dangerous condition if near static electrical discharges or other sources of ignition. Elemental sulphur is also ingested by sulphur oxidising bacteria, particularly in hot moist climates such as may be encountered at many ports or terminals. These bacterial excrete sulphuric acid, which may contribute to significant damage to valuable infrastructure.

Control of these risks is achieved typically by application of a suitable dust control agent, an acidity control agent, and by following systematic and regular maintenance and housekeeping procedures. Traditional dust suppressants are added as water-based sprays and are very effective when combined with appropriate engineering and maintenance. However, these formulations generally freeze at or near 0°C. This precludes their use in winter conditions in cold climates, where temperatures may regularly reach -40° C or even colder, causing great difficulty in controlling dust in these climatic conditions. This article describes a new class of sulphur dust suppressants which can be used in frigid climates, and which are effective at suppressing sulphur dust at extremely low temperatures.

Dust suppression methods

For dust suppressants to be effective, the entire surface of the sulphur must be wetted, and this wetting action must occur extremely rapidly. Dust suppressants are most conveniently added at conveyor transfer points, and often must be able to suppress dust by the time the sulphur impacts the next conveyor belt below. Rapid wetting action is critical as it allows small particles to agglomerate so they cannot become airborne, in addition to allowing small particles to adhere to larger particles resulting in the same effect.

As the sulphur is transferred, attrition due to particles grinding on one another and the conveyor belt or other equipment can cause additional dust to form. It is therefore imperative that the dust suppressant added to the system be able to re-wet newly created surfaces in order to continue to provide effective control. An effective dust suppressant will also provide some lubricity to the sulphur particle to minimise this attrition; however, too much lubricity may alter the handling and storage characteristics and must be avoided.

In order to effectively develop dust control measures to eliminate dust emissions, it is imperative to understand as fully as possible 1) the mechanisms of generation of the dust, 2) the variables which control the mechanism, and 3) the limits on the nature of the dust control to be used. In a sulphur transfer and storage operation, the limits of the speed, duration and efficiency of the dust control agent must be extremely well understood if successful dust suppression will occur.

Dust control measures use one or both of two general principles: prevention and collection/elimination. As mentioned previously, dust prevention measures such


PHOTOS: IPAC

Figure 1: Sulphur stacking operation from conveyor tripper stacking operation at 4,000 t/h without IPAC dust suppressant (left) and with IPAC dust suppressant (right). Of particular note in the picture on the left is that it is a wet, rainy day, indicating the poor ability of water to suppress dust.

as liquid dust suppressants do not allow dust to form at all; they generally involve controlled, precise dosing of active chemical agents that agglomerate the fine particles either with each other, or with larger particles. Dust preventatives must strike a balance between providing effective dust prevention (which will often involve adhesion and agglomeration of fine particles) and maintaining the original flow characteristics of the substrate material.

Collection/elimination measures, on the other hand, react to airborne dust to remove it after it is airborne. There are two general forms of collection/elimination systems: knock-down and filtration. Knock-down systems may involve water curtains, fogs, mists or other large-scale approaches to wetting airborne dust. The water (which may contain additives to increase performance) weighs it down and thus allows it to settle out of the air much more rapidly than it would otherwise. The water may allow agglomeration of particles in air, which enhances the rate of settling. In order to achieve complete or nearly complete dust removal, there must be an extremely high concentration of dust suppressant particles in the air relative to the amount of dust particles. This is particularly true when dealing with sulphur, as it is very hydrophobic. Water curtain and fog systems may be effective if they are properly installed, maintained and utilised in specific situations, such as open areas where other more efficient forms of dust control are unavailable. Disadvantages are that there is often a very high water use rate, as well as sensitivity to wind and other environmental conditions. It is also obvious that in cold (below freezing) conditions that water curtain, fog and spray systems cannot be employed effectively.

Filtration systems actively remove the dust particles from the air by collecting the dust-containing ambient air and physically removing the dust particles, either in a centrally located baghouse or filter stations located as needed throughout a facility. There is a tremendous variety of filter configurations and types that can be implemented, and as with water fogs and curtains these can be quite efficient when installed correctly in appropriate situations. Filtration systems are however ineffective in open areas, outdoors, or when air flow cannot be properly controlled, and often require significant ducting and high powered blowers. Air filtration systems provide only point-of-action dust reduction, and do not provide any residual or long lasting dust reduction. Power requirements for the blowers required for large air handling can also be significant costs, particularly if there are multiple points where dust collection is required. Filtration systems can nevertheless be used in extreme cold if measures are taken to prevent condensation and freezing in the filters that are used.

Liquid suppressants

Preventative measures such as liquid dust suppressants are the focus of this article. These aim to eliminate the potential for dust to form, therefore precluding the need for a system to remove it from the air. Liquid applied dust suppressants provide both point-of-application dust suppression, and also can provide significant residual action downstream. Dust preventatives are applied directly on the substrate either neat or diluted with water, in order to accomplish three things:

- Agglomeration of fines already present in the substrate, or adhesion of fines to larger particles
- Prevention or reduction of fines formation
- Capture (through agglomeration) of fines as they are generated during processing

Application is achieved through the use of pressurised spray systems, with nozzle, pump, and metering arrangements engineered specifically for the combination of substrate and process where dust is to be eliminated. With proper engineering and selection of dust suppressant, virtually all dust can be eliminated (see Figure 1).

Low temperature dust suppressants

Traditional dust suppressants suffer from a severe limitation: they are water-based formulations that freeze at or near the freezing point of water. In cold climates, the spray application of such formulations for much of the year is simply not feasible, due to freeze-up of lines, build-up of ice on equipment, and inefficiency of the dust suppressant in the cold.

IPAC Chemicals has developed a winter-grade sulphur dust suppressant technology, *Dustbind SW*, which overcomes this limitation, and can be used down to -40° C with heated supply lines (to maintain sprayable viscosity), or -20° C without heating. Dust suppression is equivalent to that of benchmark IPAC *Dustbind S5*. The freezing points and usage limits of *Dustbind SW* compared to *Dustbind S5* and representative competitive products are provided in Table 1.

Obtaining a freezing point that extends the usable temperature range to -40° C is only the first step, however. When developing new dust control products, there are two main performance criteria that must be optimised in order to ensure the best dust suppression obtainable in the field:

- Substrate wetting speed (agglomerates fines that are present)

Table 1: Use limits for low temperature dust suppressants

Product	Freezing temperature	Effective low temp use limit (heated lines)	Effective low temp use limit (unheated lines)
Dustbind SW	< -40°C	-40°C	-20°C
Dustbind S5	~0°C	-5°C	5°C
Competing technology	~0°C	0°C	5°C

Source: IPAC

PHOTO: IPAC

Figure 2: Water droplets on powdered sulphur.

- Resistance to impact dust generation (agglomeration of newly created fines)

The first requirement for effective dust control prevention is superior wetting of the product on the substrate – rapid, complete wetting is critical to ensure that all of substrate is treated with a minimum of dust control product. Incomplete wetting allows the substrate to pass the application point untreated, contributing to inefficient dust suppression, as the fines that are present are not completely treated and can escape as dust. As important as the degree to which the product is able to wet the substrate is the speed with which this wetting occurs. This speed will determine the extent to which the product is able to penetrate into the mass of substrate and wet out the underlying layers. Pure water does not wet sulphur – it is clear therefore that water alone would not be an effective dust suppression agent. Figure 2 shows water on the surface of powdered sulphur. The water will remain in place without wetting the sulphur until it is completely evaporated, never even slightly wetting the sulphur.

Wetting can be quantified by simply measuring the time which it takes a drop of test dust suppressant to completely penetrate the surface of test substrate, so that there is no bulk liquid remaining visible. This test is very repeatable, very rapid, and is extremely valuable in the initial stages of dust control product formulation and screening. A good dust suppressant should have a wetting time of less than about two seconds on powdered sulphur. Figure 3 shows the tremendous difference that can be observed in the speed of wetting of different dust suppressant formulations on ground sulphur. *Dustbind SW* is the only technology that is able to successfully wet sulphur at temperatures far below freezing; *Dustbind S5* and the competitive technology of course cannot wet substrates and act as dust suppressants at temperatures below their freezing points.

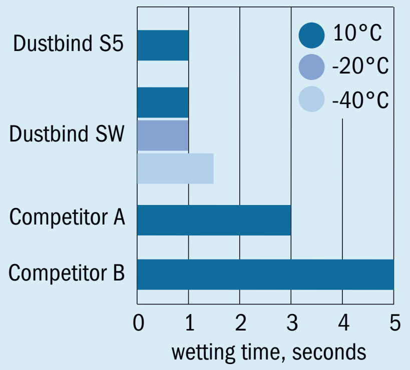
At the IPAC application labs of Dubois Chemicals Canada, we employ various techniques to directly measure the generation of dust from substrates that are untreated, or treated with different types and quantities of dust control agents. We therefore can develop a complete understanding of how a formulation should perform in the field if it is properly applied.

In order to directly measure the efficacy of the *Dustbind SW*, sulphur was treated at a 100ppm equivalent, and then subjected to a tumbler-type dust tester. This test continuously generates dust from the sulphur by means of a rotating drum, and the instantaneous levels of sulphur dust released inside the drum are monitored in real time by means of a laser-scattering aerosol measurement device. The results of the testing are provided in Figure 4. *Dustbind SW* provides similar dust suppression performance as *Dustbind S5*, and better performance than untreated sulphur, or sulphur treated with competitive products. The treatment did not alter any of the handling or physical characteristics. These results show the potential for use of *Dustbind SW* in cold climates. It should be noted that sulphur treated with water performs in an essentially identical manner to that of untreated sulphur. Water should therefore never be used alone as a dust suppressant in this manner.

Conclusion

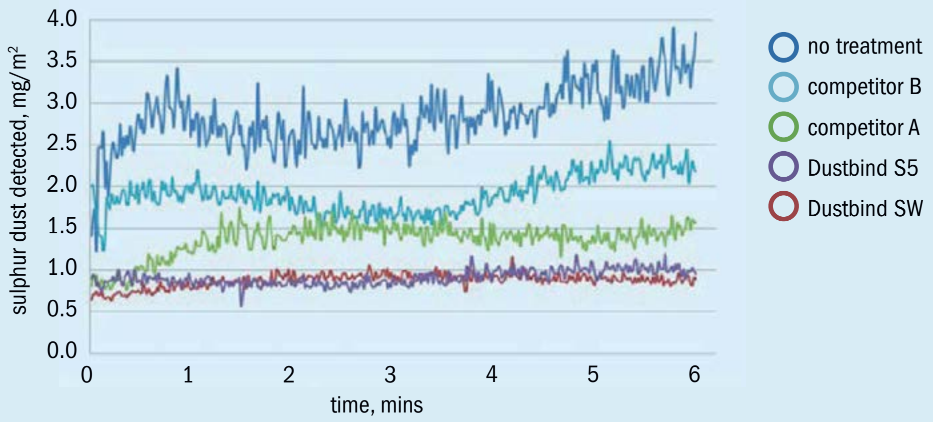
Dustbind SW technology represents a new technology that provides simple, easily applied dust suppression suitable for extreme winter temperatures such as may be routinely encountered in locations such as northern Canada, Russia and Kazakhstan. *Dustbind SW* can be freely applied at levels similar to traditional dust suppressants without affecting the flow characteristics of the sulphur, the angle of repose and therefore stacking ability, or the downstream qualities of the product.

Fig. 3: Wetting times of dust suppressant formulations at different temperatures



Source: IPAC

Fig. 4: Generation of sulphur dust using tumbler test, using different dust suppressants



Source: IPAC

TSI Sulphur World Symposium 2019

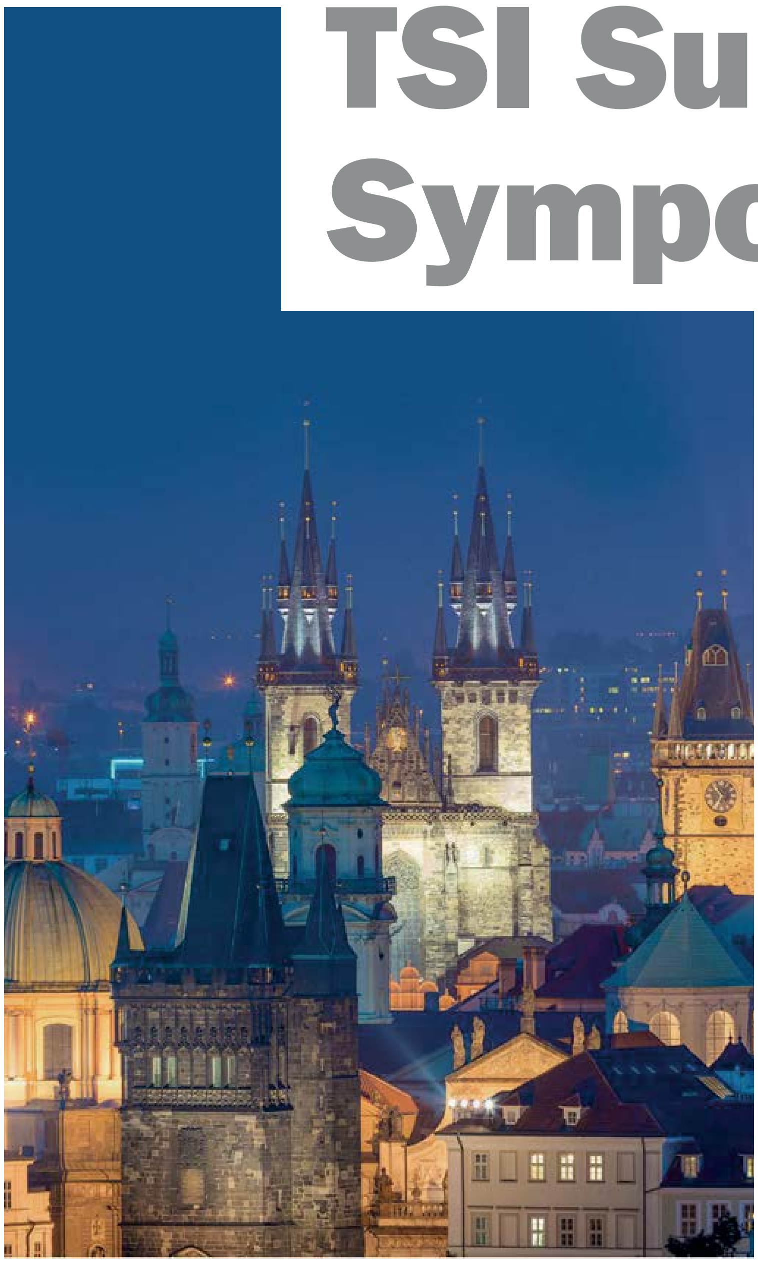


PHOTO: TAIGA / SHUTTERSTOCK.COM

Aerial view of Prague at night.

The Sulphur Institute is holding its annual meeting in Prague, capital of the Czech Republic this year from April 15th-17th.

This year, The Sulphur Institute travels to the Carlo IV Hotel in Prague this year for its Sulphur World Symposium. Featured this year, as a new addition to the event, is a Central Asian Summit that takes an in-depth look at this area of growing sulphur production and its unique transportation challenges. The following are abstracts of several of the featured presentations and speakers.

SYMPOSIUM SCHEDULE 2019

MONDAY 15 APRIL	
09:00 - 11:00	**TSI Annual General Meeting, Aida Room (TSI members only)**
13:00 - 16:00	**Central Asian Summit, Opera Ballroom**
17:00 - 18:30	**Welcome Reception**
TUESDAY 16 APRIL	
09:00 - 10:30	**Speaker Session 1**
10:30 - 11:00	**Coffee Break**
11:00 - 12:30	**Speaker Session 2**
12:30 - 13:30	**Lunch**
17:00 - 18:30	**Evening Reception**
WEDNESDAY 17 APRIL	
09:00 - 10:30	**Speaker Session 3**
10:30 - 11:00	**Coffee Break**
11:00 - 12:30	**Speaker Session 4**
12:30 - 13:30	**Lunch**

Sulphur and sulphuric acid market review

Fiona Boyd and Freda Gordon, Acuity Commodities

Acuity's presentation will review notable changes in production and consumption of sulphur and sulphuric acid, and the impact they could have on global trade flows. In 2020, there will be changes in sulphur supply as new production assets begin to ramp up. In the presentation Fiona and Freda will track progress on the numerous projects that are expected to add sulphur supply in the coming years, including new refineries in Kuwait (Al Zour) and Saudi Arabia (Jazan), both set to be operational in 2020. Some of this new supply will be offset, however, by continued declines in production in North and Latin America, for example, which will also be discussed. In the coming year, implementation of new regulation requiring lower sulphur content in refined products will come into effect. This is not just limited to the often discussed impact of the IMO 2020 mandate, but also in India, for example, 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 10 ppm.

Turning to sulphuric acid, the market was balanced-to-tight in 2018 which has carried into 2019. The presenters will review the drivers of the prevailing tight supply, such as unplanned production disruptions amid firm demand. This has required some consumers to diversify their supply sources and supported non-traditional sources of supply being traded. Market tightness has induced changes to acid trade flows, and we will look into other expected changes, such as the potential for increased availability out of China and the first import tank capacity on the west coast of North America due to be commissioned in the second half of 2019.

On the consuming side, the market will see demand for sulphur and sulphuric acid primarily from ongoing phosphate production growth, such as in Brazil. There, sulphur consumption is expected to increase by around 300,000 t in 2020. It should be noted, however, that in a longer-term view, there is potential for further phosphate rationalisation in North America which could offset some of the increased consumption in Latin America, Africa and Saudi Arabia. The presentation will also touch on the electric vehicle (EV) evolution which is seen as largely bullish for sulphur and sulphuric acid consumption related to metals.

The outlook for phosphates and what it might mean for sulphur

Allan Pickett, Fertecon

Change continues apace in the phosphate industry. New world-scale plants are being commissioned in North Africa and the Middle East; the EU looks to tighten regulations on product quality; China grapples with excess capacity and environmental issues; Latin American agriculture continues to expand with some much-needed investment in inputs; globally framers look to fertilizer use efficiency and to new products to reduce waste and improve margins. Sulphur is a core raw material, not only for the production of phosphoric acid for ammoniated phosphates, NPKs and TSP, but also for SSP. Allan Pickett, Principal Consultant for Phosphates and Potash at Fertecon will review recent developments across all phosphate fertilizers and consider what they mean in terms of future demand and supply. The presentation will look at proposed developments and the likelihood that they will be implemented, and the overall scope for new projects. The overall phosphate supply forecast will then be assessed in terms of the implications for future sulphur demand looking forward to 2024.

Southern Africa: sulphuric acid production, upwards and onwards

Steve Sackett, TradeCorp Africa

Southern Africa has rich mineral deposits which are being extracted at a rapidly growing rate. This extraction requires sulphuric acid – lots of it – and thus the production of sulphuric acid (and subsequent imports of sulphur) in Southern Africa has increased exponentially from the early 2000s and will continue to grow well into the 2020s – fuelled mostly by growth in copper and cobalt extraction in the central African copper belt. This presentation will focus on the four main acid-producing countries – DRC, Zambia, South Africa and Namibia and will cover:

- Historical and projected sulphuric acid production until 2025
- Demand for sulphur as this will increase from current levels (1.2 million t/a) to over 2 million t/a
- Sulphur burners versus smelter production
- Movements of sulphuric acid between countries
- A look at the fine balance between involuntary production and sulphur burning, as well as surplus acid – where will it go?
- Logistics challenges in Africa as many of the countries are land-locked and far from a port – some sulphur is travelling nearly 3,000 km to its consumption point. As an example, logistics costs make up more than twice as much as the c.fr cost of sulphur, and must travel mostly by road transport, as rail systems are dilapidated. Hard borders lead to border delays and queues. There is also the question of choice of port of entry – how to get sulphur to its final consumption spot.

Ma'aden Umm Wu'al sulphuric acid and power plant

Michael Angeli, SNC-Lavalin

SNC-Lavalin is a longstanding leader in the sulphuric acid industry, having successfully installed more than 60 plants around the world over the past 25 years. One of the largest sulphuric acid complexes in the world – the Umm Wu'al Sulphuric Acid and Power Plant Project for the Saudi Arabian Mining Company (Ma'aden) – was recently successfully commissioned. SNC-Lavalin provided full engineering and execution services and used industry-leading technology from MECS-DuPont.

The project was part of Ma'aden's Waad Al Shamal Phosphate Project to convert phosphate ore into various end products, primarily for the agricultural sector. The overall project facility is comprised of: three sulphur-burning sulphuric acid plants, each rated at 5,050 metric tonnes per day; one power plant using two steam turbine generators each producing 76MW of electricity; associated infrastructure and utility facilities; and associated tie-ins and interfaces with the existing plant.

Central Asian Summit

Central Asia and the Caspian Sea region are known for their energy-rich reserves. In the past decade, the increase in sulphur supply has highlighted this region as one of the sulphur export markets globally. The geography of the region imposes several challenges with getting product to market. The Central Asian Summit will highlight these challenges through discussion and dialogue with speakers from within the region and others who monitor the region's energy sector. This speaker session will examine the political and economic factors that influence business in the region, as well as an update on sulphur-related projects in and around the Central Asian States, analysis of regional sulphur supply and demand including Russia, risk mitigation measures for sulphur handling, and transportation and infrastructure challenges for exporting sulphur to global markets.

Central asia: sulphur supply and demand

Meena Chauhan, Argus Media

Recent developments in the oil and gas sector have led to major shifts in supply in the Central Asian region but the remote location of some projects has led to some challenges in bringing sulphur to the market. In Kazakhstan, trade has seen a significant boost due to the start-up of a long awaited Kashagan project. This paper will provide an overview of supply and demand in some of the key markets in Central Asia including Turkmenistan, Kazakhstan and Uzbekistan. It will take a look at how the market balance in the region has been impacting trade flows and what is next on the horizon for production changes.

A look at sour oil and gas projects within the Caspian Sea region

Richard Hands, BCInsight Ltd

The Caspian Sea area and surrounding states of Central Asia hold some of the world's largest oil and gas fields, many of them highly sour. However, development of these fields has been complicated by geology, technical issues, politics and the logistical and consequent economic difficulties caused by the remoteness of the locations. This article looks at the major oil and gas developments within the region and the potential impacts on sulphur production, including key decisions on sulphur storage, sale or transport versus, for example, re-injection of highly acidic gases into wells.

Sulphuric acid from non-condensable gases

New wet gas sulphuric acid technology to produce sulphuric acid from the incineration of pulp mill non-condensable gases has been operating continuously since 2017, reducing sulphurous emissions at the Äänekoski pulp mill in Finland. The internally produced sulphuric acid can replace purchased acid at several locations within the mill. **Naveen Chenna** of Valmet Technologies Inc. describes the new process and its advantages.

Sulphur is an essential chemical element in kraft pulp mills and it actively participate in reactions with wood chips to produce pulp. Sulphur is present in black/white liquors and discharge waters and escapes the pulp mill processes as non-condensable gases (NCGs)[1]. Traditionally, NCGs are carefully collected and incinerated either in a recovery boiler/power boiler/lime kiln or separate NCG boiler. In many cases oxidised sulphur in flue gas is not recovered and thus it increases the emission levels of mill.

Valmet has developed wet gas sulphuric acid production technology from the incineration of NCGs in which the produced sulphur dioxide from NCG incineration is oxidised to sulphur trioxide in a catalytic converter and condensed along with water vapour to produce sulphuric acid.

Typical pulp mill processes

Active chemicals containing sulphur (S) and sodium (Na) as the main elements play a vital role in chemical pulp mills. In any given mill process, Na/S exists as a combination of different chemical forms, i.e. in cooking as Na_2S, in black liquor as Na_2S, Na_2SO_4 and Na_2SO_3, in the dissolving tank mainly as Na_2SO_4, Na_2SO_3, and many other forms. The efficiency of a pulp mill is defined by the amount of pulp it produces by maintaining its active chemical recycling process. However, the recycling of chemicals is disrupted due to the complexity of the chemicals coming in and out of the mill processes. Many mills around the world are facing Na/S chemical balance problems, irrespective of whether they are old or new, softwood or hardwood mills.

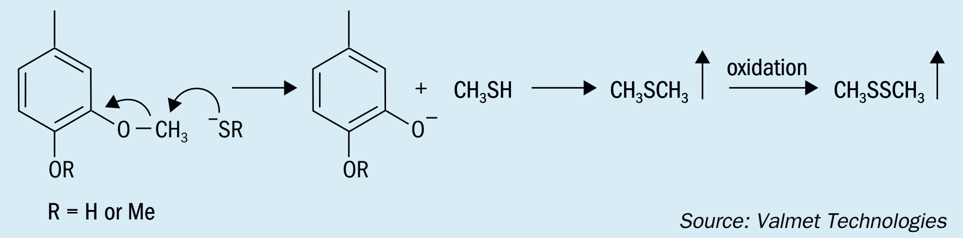
Sulphuric acid is an important chemical at pulp mills. It is used in several processes such as in tall oil production at softwood mills, in the hot sulphuric acid stage mainly at hardwood mills and for chlorine dioxide generation at almost all mills. In case of new lignin extraction plant installations, the sulphuric acid usage at pulp mills will be much greater and the sulphur balance of the mill may face challenges.

In order to control mill sulfidity, it is common practice to purge sulphur-rich streams, e.g. ash from the recovery boiler separated by an electrostatic precipitator (ESP) and neutralised spent acid from the chlorine dioxide plant. Recovery boiler ash mainly contains Na_2SO_4 which means that significant quantities of sodium are lost when sulphur levels are controlled. Due to the loss of sodium with the ESP ash, sulphur-free sodium must be added to the system. Therefore, sodium carbonate or most often sodium hydroxide is added, since sodium hydroxide is easier to handle and is an active chemical. Sodium hydroxide is however expensive due to the high power consumption in its production. Thus, the intake of sodium increases the pulp mill operating costs.

Environmental and economic forces have been reducing ash purging and the consumption of fresh water. Additionally, improved pulp washing has reduced the loss of chemicals with the pulp leaving the washers. Reducing sodium loss from the washing process is more difficult to achieve since sodium is adsorbed on the fibre that leaves the closed liquor cycle. Although these methods are applied at some modern mills, they still face difficulties to control the sulphur. One of the trends in kraft pulping is to create valuable side streams from the process. Such streams are in many cases created by primary acidification with sulphuric acid. Examples include tall oil production and lignin extraction. Sulphur from these processes increases the sulphur load on the mill recovery cycle and therefore internally produced sulphuric acid will close the mill chemical balance, and the acid can be used in ash leaching, tall oil production or chlorine dioxide production. At a pulp mill, sulphuric acid can be produced from non-condensable gases.

These undesirable sulphurous gases can be found in many areas of the pulp mill. The levels and composition of reduced

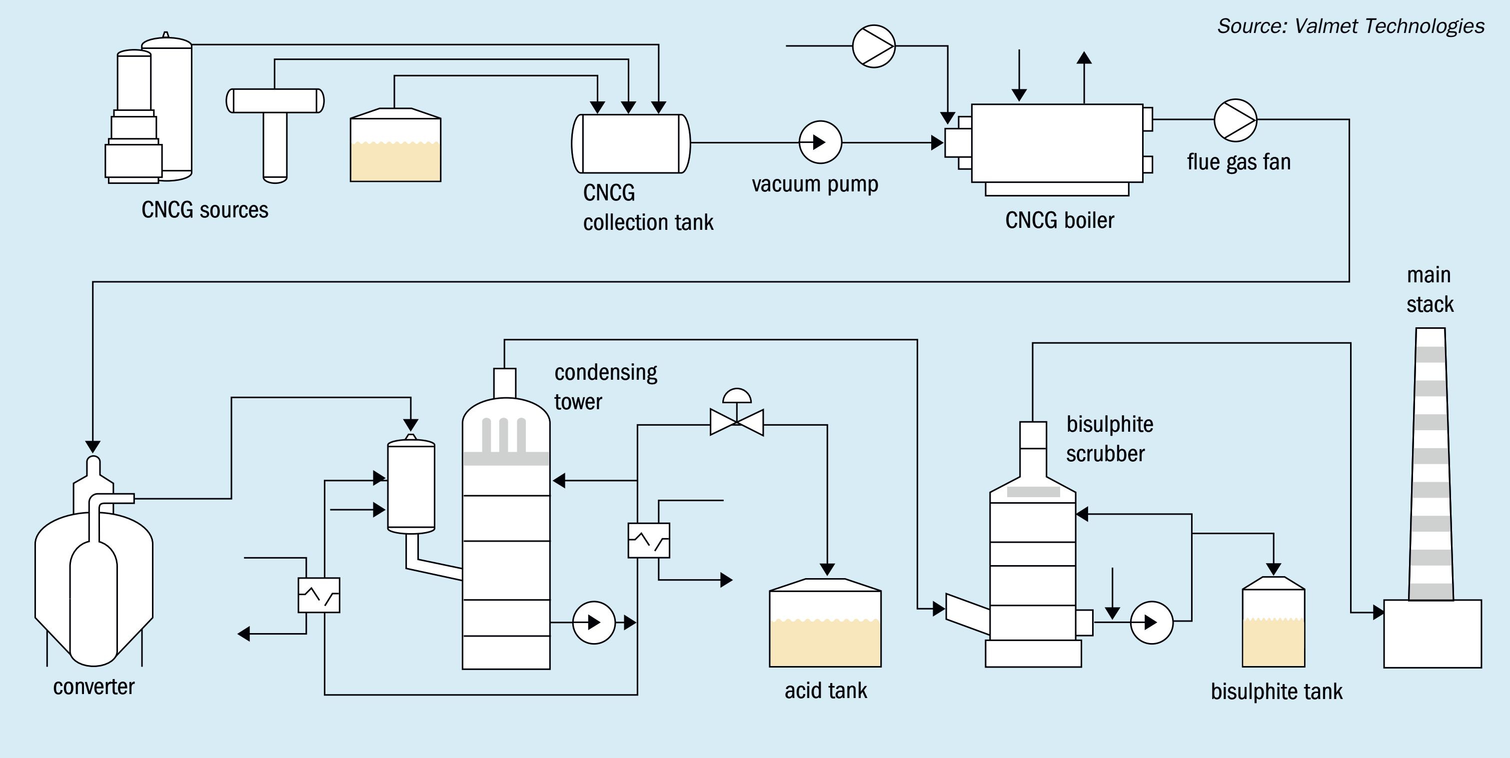
Fig. 1: **Formulation of mercaptans from nucleophilic demethylation of dissolved lignin moieties**



Source: Valmet Technologies

Fig. 2: Process overview of sulphuric acid plant at pulp mill

Source: Valmet Technologies



sulphur in NCGs varies considerably throughout a kraft pulp mill and from one mill to another. Great efforts must be made to collect these NCGs to convert them to less harmful compounds by oxidation. The reduced sulphur compounds cause a pungent smell in the mill's surroundings and oxidised sulphur contributes to the large-scale acidification of soil, which has a negative impact on vegetation and biodiversity.

Non-condensable gases mainly contain hydrogen sulphide (H_2S), methyl mercaptan (CH_3SH), dimethyl sulphide (CH_3SCH_3), dimethyl disulphide ($CH_3S_2CH_3$) and other reduced sulphur compounds. These harmful gases[2] are formed mainly in the kraft cooking process where strong nucleophile HS^- causes a partial demethylation reaction at the methoxyl groups of lignin and the reaction yields methyl mercaptans[3]. The formed methyl mercaptan is itself a strong nucleophile, and reacts further with another methoxyl group to yield dimethyl mercaptan (Fig. 1).

Regulatory pressure has increased since the early 1990s and has resulted in lower emission levels for NCGs. The collection, combustion and scrubbing of the remaining NCGs has become a standard procedure. It is now accepted that through sound design, the safe and efficient collection of NCGs can be accomplished. Environmental authorities have enforced stringent laws to curb NCG release to the environment and most modern mills have practically eliminated or significantly reduced NCG emissions to the atmosphere. This article describes a success story built on adopting the principles of biorefinery concepts and how the toxic NCGs are converted to very good quality sulphuric acid that can be used in several pulp mill processes.

Sulphuric acid plant

To minimise odorous emissions, NCGs are usually collected and incinerated. At some mills, a bisulphite scrubber is used to recover sulphur after incineration in the form of sodium bisulphite. Limited use of bisulphite restricts the amount of active sulphur that could potentially be converted into different active chemicals to be used in the mill processes. Therefore, a new system for sulphur recovery has been designed and built by Valmet Technologies Inc. and is being operated at Metsä Fibre Äänekoski Bioproduct mill in Finland. At this plant, the sulphur from NCGs is used to produce sulphuric acid.

CNCG incineration

Concentrated non-condensable gases (CNCGs) are collected and led to a collection tank, from which they are taken to a separate incinerator (Fig. 2). Depending on sulfidity and heat treatment in the evaporation and cooking, the sulphur release to NCGs is between 3 and 7 kg/ADT as elemental sulphur. In the separate incinerator, total reduced sulphur compounds in the CNCGs are oxidised into SO_2. The burner and the boiler are otherwise designed as for traditional CNCG incineration, but residual oxygen and flue gas exit temperature are adjusted to an optimum level. One limit is set by the catalyst process and another by the boiler heat surfaces that require a high enough temperature to avoid corrosion.

SO_2 oxidation process

The flue gas from the boiler is led to a catalytic reaction vessel. The reaction vessel is a cylindrical tank filled with solid catalyst. The catalyst oxidises SO_2 by using excess oxygen supplied through combustion air into SO_3 by means of an exothermic reaction (1). The temperature of the flue gases is higher after the catalytic oxidation and is very corrosive due the presence of SO_3 and water vapour that may form sulphuric acid, if the temperature is reduced at any point.

$$2SO_2 + O_2 \rightarrow 2SO_3 + \text{heat} \qquad (1)$$

Wet gas condensation process

Flue gases from the catalytic converter are passed into a condensing tower or quench tower (Fig. 2). Flue gases are cooled down in the quench tower and then passed to a second condensing tower. To protect the system from overheating, the gas temperature must be adjusted to the proper level before the gases enter the tower.

In the concentration tower liquid is recirculated through a plate heat exchanger. The heat exchanger cools the liquid down, and the cooled liquid is pumped back to the tower. The temperature of the flue gases is reduced with the cooling liquid and the SO_3 in the flue gases reacts with H2O to produce sulphuric acid (2).

$$SO_3 + H_2O \rightarrow H_2SO_4 + \text{heat} \qquad (2)$$

The acid concentration in the concentration tower depends on the partial pressures of SO_3 and H_2O in the flue gas. As the flue gas cools down inside the tower, water is also condensed from the flue gas. The final acid concentration depends on the amount of sulphur in the CNCGs before incineration. The produced acid is quite aggressive to the contact materials, and the concentration tower must therefore be designed with acid resistant materials. Acid is taken out of the concentration tower circulation after the heat exchanger and passes to an acid storage tank. After the concentration tower, the gases may contain very low amounts of SO_3 aerosols which need to be removed before the gas can be treated further. The biggest challenge in this kind of sulphuric acid production is the end concentration of the acid, 50-70 wt-%, which is the most aggressive concentration, so all materials must be carefully selected.

Tail gas scrubber

A tail gas scrubber with sodium hydroxide addition can be used to wash the residual SO_2 from flue gases before being released to the environment. During sulphuric acid production, the residual SO_2 levels are very low as most of the SO_2 is oxidised and converted to SO_3. Alternatively, flue gases from the boiler can be diverted directly to the scrubber, in which case concentrated sodium bisulphite is produced and can be used directly at the pulp mill. The scrubber also washes out any other contaminants before the flue gas reaches the stack.

NCG-based acid plant and start-up

The sulphuric acid plant (Fig. 3) based on incineration of NCGs was developed by Valmet and is operated at the Äänekoski Bioproduct mill in Finland. The plant consists of a CNCG incinerator, catalytic converter, condensing tower, and a bisulphite scrubber including product storage tanks. The production capacity of the plant is approximately 35 t/d of sulphuric acid. Higher quantities can be produced depending on the sulphur content of the incoming non-condensable gases. This is the world's first larger scale sulphuric acid plant that is being operated at a pulp mill. The high quality of the sulphuric acid produced is suitable for use in any part of the mill.

Fig. 3: **Sulphuric acid plant model at Metsä group Bioproduct mill, Äänekoski, Finland**

Source: Valmet Technologies

The sulphate load in the nearby waterways has seen a dramatic decrease.

The start-up of a new sulphuric acid plant at a pulp mill is challenging due to the corrosive and hazardous nature of SO_3 and H_2SO_4. It is important therefore that the properties of these chemicals and the process conditions are well understood right from the design phase of the plant. In addition, the process must be in coherence with all other mill processes, because of its versatile role at the pulp mill. The produced acid can be used in bleaching, chlorine dioxide production, tall oil production, pH control and in the waste water treatment plant. Internally produced sulphuric acid reduces the cost of externally purchased acid, has environmental advantages and helps in closing the mill chemical balances. The sulphuric acid plant is a step closer to achieving the realisation of future biorefinery concepts.

Conclusions

The production of sulphuric acid from pulp mill non-condensable gases enables the bioproduct mill to become nearly self-sufficient in sulphuric acid usage. The sulphuric acid plant brings significant environmental advantages, for example, the amount of sulphate going to the mill's effluent treatment plant has been reduced and the sulphate load in the nearby waterways has seen a dramatic decrease. The CNCG incineration plant can be used as a back-up boiler for producing process steam by incinerating CNCGs, tall oil pitch and/or liquid methanol. This innovative plant can produce sulphuric acid and bisulphite simultaneously depending on requirements. The internal recycling of chemicals also saves on the external purchase of 350 truckloads of acid per year.

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WATER
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TGTU re-start-up at Mellitah Complex

The Claus tail gas treatment unit (TGTU) at the Mellitah Oil & Gas BV complex was successfully re-commissioned in January, 2018. **Ciro Di Carlo** of Siirtec Nigi describes the sequence of operation successfully carried out under Siirtec Nigi guidance to bring the TGT unit on stream, on a continuous and stable basis, under uncommon circumstances.

The Claus tail gas treatment unit (train 3), part of the acid gas treatment and sulphur recovery facilities installed at Mellitah complex, Libya, owned and operated by Mellitah Oil & Gas BV (MOG), was successfully re-commissioned and put on stream under Siirtec Nigi supervision in January, 2018.

Siirtec Nigi, as licensor of the acid gas treatment and sulphur recovery unit, was involved in the original commissioning and start-up of the plant in 2004. After a few years of good operation, the plant started to suffer from a lack of preventative maintenance and shortage of spare parts due to the geopolitical and economic situation of the country caused by the 2011 civil war and subsequently by the deep instability and difficulties faced by foreign companies that were still trying to work in that area.

The tail gas treatment unit was most affected by the situation and there were major difficulties in maintaining its satisfactory operation. The TGTU was therefore shut down and the Claus tail gas was diverted to the thermal incinerator, resulting in large emissions of SOx into the atmosphere which had a negative impact on the local environment.

No proper precautions were taken to preserve the unit during its long-term shutdown.

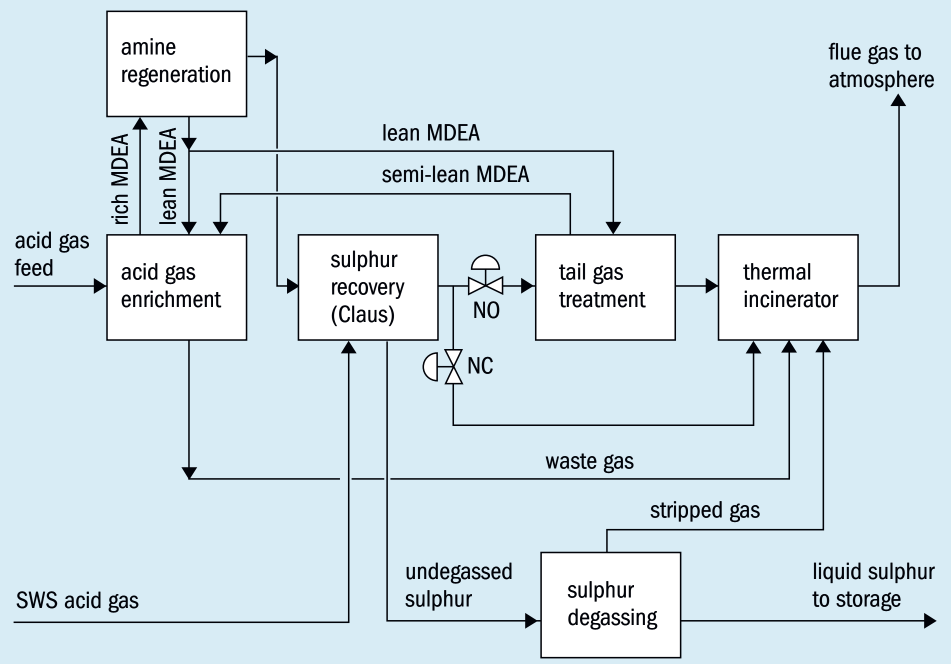
In recent years, the Libyan authorities have introduced more stringent environmental regulations which required MOG to lower the SOx emissions from the incinerator stack.

Siirtec Nigi provided technical supervision and led all re-commissioning and re-startup activities as licensor of its patented High Claus Ratio (HCR™) process.

The unit ran continuously at fairly stable conditions following the successful start-up and was consequently handed over to the MOG operation team with deep client satisfaction.

The salient features of the Siirtec Nigi HCR™ process make it very attractive in gas treatment plants where no external hydrogen source is available, and hydrogen is self-generated in the Claus section without requiring a reducing gas generator (RGG).

Fig. 1: **Mellitah complex, acid gas treatment and sulphur recovery**



Source: Siirtec Nigi

Plant configuration

The plant (Fig. 1) comprises three parallel and independent trains, each consisting of the following process units:

- acid gas enrichment (AGE) and amine regeneration (ARU);
- sulphur recovery;
- sulphur degassing;
- tail gas treatment (TGT);
- incineration;
- sour water stripper (SWS) - two parallel and independent trains.

The offsite units provided are:

- amine storage;
- sulphur storage;
- sulphur solidification.

The nominal capacity of each train is 270 t/d in terms of produced liquid sulphur.

The operating philosophy foresees two trains running at full capacity with the third one kept in hot standby, or shut down for maintenance if needed.

Fig. 2: **Claus unit SRU**

Fig. 3: **Tail gas treatment unit (TGTU)**

PHOTOS: SIIRTEC NIGI

Process description

AGE and ARU

The acid gas coming from battery limits (BL) consisting of approximately 9 vol-% H_2S and 85 vol-% CO_2 is fed to an amine absorber to remove most of H_2S prior to sending the waste gas to the SRU incinerator. The residual H_2S content in the waste gas is about 180 ppm vol.

The absorbing medium is a 50 wt-% MDEA solution. The rich amine leaving the absorber bottom is regenerated in the amine regenerator and recycled back to both the AGE absorber and the TGT absorber. The amine acid gas from the regenerator top contains about 31 vol-% H_2S and is suitable to be processed in the downstream SRU.

Sulphur recovery (Claus)

The amine acid gas from the ARU is fed to the sulphur recovery unit (SRU) based on the Claus process (Fig. 2) and consisting of:

- a thermal stage, where H_2S is oxidised to SO_2 and most of the Claus reaction leading to elemental sulphur formation is accomplished in the thermal reactor. Generated sulphur condensed in the waste heat boiler and the first sulphur condenser is routed to the sulphur pit through dedicated hydraulic seals.
- a catalytic stage consisting of two Claus reactors, where the Claus reaction is further completed. Generated sulphur condensed in the second and third sulphur condensers is routed to the sulphur pit through dedicated hydraulic seals.

It should be noted that saturated high pressure steam (HPS) generation takes place in the Claus waste heat boiler, operated at 46 bar g. The generated HPS is used for process heating purposes (acid gas feed, combustion air, first/second Claus reactor re-heaters). Hence, there is no need for in-line burners. The balance generated HPS is sent to the heat recovery section of the incineration unit then superheated and exported to BL at the required pressure/temperature levels.

Sulphur degassing

The produced sulphur is collected in a pit then fed to the degassing system through vertical submerged pumps. The process, licensed by Siirtec Nigi, basically consists of H_2S stripping by means of air coming from the Claus combustion air blowers, taking place in a tray tower installed in the degassing box. The degassed sulphur is then collected and delivered to the main storage tanks.

Tail gas treatment

The Claus tail gas leaving the Claus unit is fed to the TGTU (Fig. 3) based on the HCR™ process and consisting of:

- a hydrogenation stage, where all sulphur and sulphur-bearing compounds are reduced to H_2S. The required hydrogen is generated in the Claus thermal reactor when operated in "High Claus Ratio" (HCR™) mode at reduced combustion air vs acid gas ratio.
- a cooling stage, where the process gas leaving the reducing reactor is cooled down to about 40°C via direct quench by circulating waste water in the water removal tower (WRT). Most of H_2O contained in the process gas is condensed in the meantime, thus increasing the driving force for mass transfer taking place in the downstream TGT absorber and allowing a reduced size of the absorber itself.
- an absorption stage, where the H_2S contained in the process gas is removed by in the TGT absorber. Lean amine solution from ARU is used as absorbing medium. The treated gas from absorber top, having an about 180 ppm vol. residual H_2S content is sent to the incinerator. The semi-lean amine from tower bottom is sent back to the AGE Unit and fed to the AGE absorber at an intermediate tray.

The reducing reactor utilises a cobalt molybdenum based catalyst TG-103 supplied by Axens which requires a 280°C inlet gas temperature. Such a high temperature is accomplished by using 355°C superheated HPS from the incineration unit heat recovery section.

Incineration

The treated gas from the TGT absorber is sent to the thermal incinerator (Fig. 4) consisting of:

- a thermal stage, where residual H_2S is oxidised to SO_2 at about 700 °C to comply with Libyan environmental limits.
- a heat recovery section, equipped with a steam superheater and high pressure waste heat boiler coils, where the incinerator flue gas sensible heat is cooled down to 400°C. Waste heat recovery allows generation and super-

Fig. 4: **Incineration**

Fig. 5: **Strahman sampling valve**

PHOTOS: SIIRTEC NIGI

heating of HPS, which is exported to BL at the required pressure/temperature levels.

- a stack, from where the flue gas is safely discharged to the atmosphere.

Sequence of events

The activities leading to the successful recommissioning and start-up of the TGTU (train 3) were carried out in three steps:

- site survey (all trains) and plant inspection – September 2017;
- TGTU Train 3 precommissioning – November 2017;
- TGTU Train 3 commissioning and start-up – January 2018.

Site survey and plant inspection

A site survey was carried as part of the requested services.

All units were checked and a list of recommended actions was handed over to the client together with a set of operating guidelines aimed to enhance the SRU performance.

Only those recommendations and actions directly or indirectly affecting operation of the TGTU are described herein.

AGE and ARU

A trim cooler consisting of 12 shells is provided to complete cooling of the lean amine from the regenerator down to 45°C, suitable for proper acid gas absorption in the AGE and TGTU absorbers.

Many of them were out of service due to leakages. In addition, an abnormal presence of chlorides was suspected in the cooling water. Insufficient lean MDEA cooling effect was therefore experienced especially during summer time.

Actions for repairing the leaks were carried out and the cooling water pH and quality was kept under closer monitoring and control.

Sulphur recovery (Claus)

The air demand tail gas analyser (H_2S/SO_2 analyser) was no longer in service. Hence, the SRU was operated without a reliable and continuous response.

Besides decreased sulphur recovery yield and damage to the catalyst and equipment due to incorrect H_2S/SO_2 ratio, which can potentially lead to Claus catalyst poisoning and acid condensation, a continuous and reliable air demand analyser response is mandatory while operating in HCR mode with TGTU on stream.

The operation mode was optimised by carrying out quick field analyses of H_2S and H_2S+SO_2 by using Dräger tubes.

The causes for the analyser plugging were investigated and identified as abnormal sulphur carryover in the vapour phase, as detected while opening the Strahman sampling valve (Fig. 5), which led to the analyser's impulse lines plugging.

Instructions to enhance the air demand analyser's impulse lines heating system and relevant thermal insulation were given (Fig. 6).

It was suggested that the status of the demister installed at the sulphur coalescer outlet should be checked and that a steam heating coil should be provided at the demister bottom.

The temperature of the boiler feed water fed to the final sulphur condenser as cooling medium was 140°C, significantly higher than the 120°C foreseen during design. As a result, sulphur condensation was less than expected and sulphur vapour carryover as already described took place. The system was investigated and the third condenser which lowers the BFW temperature to 120°C was found to be out of service due to extensive leakages.

Tail gas treatment

According to the information provided by MOG operating personnel, the procedure for a proper planned TGTU shutdown was not carried out. Moreover, no proper precautions such as bottling the unit under inert atmosphere were taken to preserve the unit after shutdown.

In view of this, the WRT manholes were opened and the internals inspected. Significant quantities of sulphur powder were found (Fig. 7) on the top distributor, trays and tower bottom. Several valves were missing on the valve trays provided in the tower's lower section. Some cracks were also detected on trays and shell weldings.

Sulphur powder was also found also in the suction line of the waste water pumps and in the waste water filters. Filter "A" baskets were found to be damaged and were replaced.

The WRT was thoroughly cleaned. The top section packing had to be removed for this purpose.

The TGTU absorber was inspected and found to be in good condition.

Advice was given for replacement of the hydrogenation catalyst still present in the reducing reactor since the last shutdown.

Fig. 6: **Air demand analyser impulse lines**

PHOTOS: SIRTEC NIGI

Fig. 7: **Sulphur powder from WRT**

Spare catalyst (TG-103 supplied by Axens) stored in drums at MOG's open warehouse since 2009 was available. Several drums were found to be corroded and the catalyst polluted (Fig. 8). Catalyst samples were taken from the drums that had not corroded and sent to Axens for analysis.

Axens confirmed the suitability of non-contaminated catalyst stored in those drums found not damaged.

The recycle gas fan had been out of operation for years together with the TGTU. A first trial run was carried out, but the machine had to be stopped because of high vibrations. The casing was inspected, found to be rusty and then cleaned. The alignment was also redone and then the machine could finally be put back in operation.

Precommissioning

Spent TGTU catalyst unloading and replacement

The spent TGTU catalyst was unloaded from the reducing reactor and replaced by fresh catalyst after clearance from Axens.

Catalyst passivation was carried out prior to opening the reactor manholes and proceeding with catalyst unloading. The passivation was carried out by feeding air from the Claus combustion air blowers through a 2-inch dedicated line.

The 2-inch oxidation air line and the 2-inch acid gas line for fresh catalyst presulphiding were thoroughly blown backward with nitrogen prior to proceeding with passivation.

The catalyst was most likely already passivated having been left in the vessel for years without any preservation and perhaps being contaminated with oxygen. However, since the planned shutdown procedure was not applied at that time, the presence of sulphur entrained on the catalytic layers was strongly suspected. Hence, the passivation consisting of slowly feeding oxygen through the 2-inch air piping line had the purpose to either oxidise the catalyst or to burnout under monitoring any residual entrained sulphur.

An inert gas hot recirculation was established through the recycle gas fan by commissioning the superheated HPS to the TGTU gas re-heater. A temperature of about 240°C achieved at the reducing reactor inlet.

Oxidation air was fed to the reactor by commissioning the 2-inch dedicated line and a slow temperature increase was soon detected. The combined catalyst oxidation and sulphur burnout process lasted about 24 hours. A temperature rise up to about 300°C was observed during operation. Once the temperature wave passed through the catalytic bed, the operation was considered completed and the bed was gradually cooled down to about 40°C.

Finally, the reactor manholes (Fig. 9) were opened and the passivated catalyst was safely unloaded and replaced with fresh catalyst.

Waste water and amine lines flushing

After completing the activities on the WRT and the box-up of manholes, the entire waste water circuit was cleaned by establishing a cold recirculation. Temporary strainers were installed on the pump suction lines during this operation.

Flushing water was discharged after completion and the system was re-filled with demineralised water.

Scale phenomena were found in the incoming lean amine outgoing semi-lean amine lines to and from the TGTU absorber. Amine lines were thoroughly flushed stepwise with fire water. Control and on/off valves were temporarily dismantled and replaced by spool pieces prior to proceeding with water flushing.

Flushing water was discharged after completion and the entire system including the absorber was dried and purged with nitrogen.

Commissioning and start-up

TGTU catalyst pre-sulphiding

The fresh catalyst is supplied as cobalt and molybdenum oxides (CoO and MoO_3).

The active components for TGTU reduction reaction catalysts are cobalt and molybdenum sulphides (CoS and MoS_2).

Presulphiding in the presence of H_2 and H_2S is therefore required to achieve active (reduced) status.

The conversion of the cobalt is fairly straightforward:

$$CoO + H_2S \rightarrow CoS + H_2O$$

The conversion of the molybdenum is more complicated because the molybdenum changes oxidation number from six to four. This behaviour requires a reducing agent (hydrogen) to complete the sulphiding process because hydrogen sulphide alone does not provide enough hydrogen:

$$MoO_3 + 2H_2S + H_2 \rightarrow MoS_2 + 3H_2O$$

These reactions are exothermic; the sulphiding process should therefore be carried out under careful monitoring and control to prevent any localised overheating (hot spots).

Choice of pre-sulphiding procedure

Hydrogen is self-generated in the Claus thermal reactor during normal operation by operating the SRU at HCR™ mode (i.e. by keeping the H_2S/SO_2 ratio in the tail gas significantly higher than the conventional 2).

A dedicated 2-inch line from the amine acid gas separator was available to provide the required H_2S.

A hydrogen line for pre-sulphiding was not provided due to unavailability of a continuous hydrogen source at Mellitah complex as well as in other gas fields.

Fig. 8: **Contaminated vs non-contaminated catalyst**

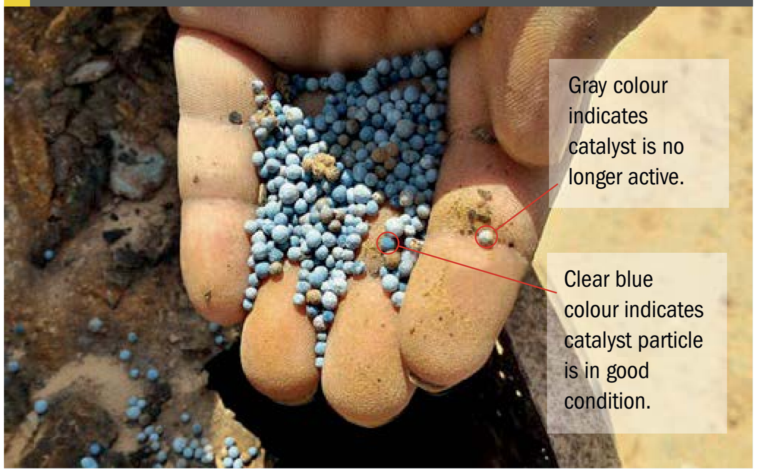


Fig. 9: **Reducing reactor top manhole**

PHOTOS: SIIRTEC NIGI

Different pre-sulphiding options were therefore analysed and discussed.

Direct pre-sulphiding with Claus tail gas

This procedure implies the use of hydrogen generated in the thermal reactor operated in HCR™ mode as mentioned above.

At first sight, this option seemed to be the simplest one. However, unconverted sulphur carryover from the reducing reactor during the first hours of operation after TGTU line-up were envisaged to occur prior to achieving full catalyst activation This would have potentially led to sulphur solidification in the WRT.

Thermal reactor as reducing gas generator

This procedure implies the operation of the thermal reactor in fuel gas mode at slightly sub-stoichiometric ratio, as a conventional RGG, and in fact it was applied during the first TGTU start-up in 2004.

This procedure could not be applied as one of the three trains was already shut down for maintenance: the acid gas load currently processed requires two trains in operation. Hence, the gas quantity exceeding the nominal capacity of a single train would have had to be continuously flared. This choice was therefore ruled out.

Temporary external hydrogen source

Due to the unsuitability of the previously mentioned options, it was decided to provide a temporary external source of hydrogen.

A half-inch temporary line connected to a vent installed upstream of the reducing reactor, equipped with a globe valve and a pressure gauge, was arranged for this purpose.

A rack of 50-litre hydrogen cylinders at 200 bar g was also arranged to provide the required quantity of reducing gas.

Pre-sulphiding operation

The hydrogen analyser at the WRT was checked, recalibrated and put in service.

Similarly, the water pH in-line analyser on the waste water circulation pumps was checked and found reliable and ready to start. The TGT gas circuit was thoroughly purged with nitrogen to achieve about 0.2 vol-% residual oxygen content.

The recycle gas fan was re-started and gas recirculation was established, keeping about 0.1 bar g pressure at the WRT gas outlet.

The waste water circulation pumps were started-up and a cold water recirculation throughout the WRT was established.

The reducing reactor catalytic bed was gradually heated up to 190°C by commissioning the superheated HPS to the upstream TGT gas re-heater.

The pre-sulphiding operation commenced by supplying hydrogen to the TGT pre-sulphiding circuit from the hydrogen cylinder rack via the temporary half-inch line provided for that purpose.

H_2S-containing acid gas was fed through the 2-inch line from the AAG separator ten minutes later following first detection of hydrogen in the circuit. The analyser response was checked vs. the calibration gas and found to be correct.

The reactor inlet temperature was increased up to 200°C following the admission of hydrogen to the unit.

As lab facilities were not available, the H_2S content at the reactor inlet and outlet was checked through dedicated Strahman valves by using H_2S Dräger tubes.

Both the H_2 and H_2S content at the reactor outlet were about 0.5 vol-%. during the first hours of pre-sulphiding.

A temperature increase of about 15°C was observed through the catalytic bed, confirming that the pre-sulphiding process was taking place.

The reactor inlet temperature was progressively increased up to 260°C in 20°C steps.

An increase of up to about 2-3 vol-% was observed in both the H_2 and H_2S content at the reactor outlet.

The temperature wave passed through the reactor and an average temperature of about 264°C was observed through the catalytic bed. Both H_2 and H_2S valves were shut and the unit was kept under observation for a couple of hours without any changes. The pre-sulphiding operation was then considered successfully completed.

A six-hour nitrogen purge was established to remove any residual H_2 and H_2S, and the TGTU was kept in hot re-circulation mode, ready for line-up to the upstream Claus unit.

TGTU start-up

The amine solution to and from the TGT absorber was commissioned.

The MDEA content was checked and found to be about 42 wt-%, quite a deviation from the 50 wt-% design figure but still acceptable.

Lab analyses on the acid gas feed to AGE and SRU were carried out prior to proceeding with start-up. Results are shown in tables 1 and 2.

The operation mode of the Claus unit was adjusted to HCR mode: the combustion air flowrate was gradually decreased in order to achieve a significantly high H_2S/SO_2 ratio, suitable to generate the hydrogen quantity required for the TGT reducing reactor.

The accuracy of the air demand analyser response was checked by carrying out a quick field analysis through Dräger tubes.

Table 1: **Acid gas feed to AGE**

Component	vol-%
H_2S	7.73
CO_2	83.64
N_2	7.98
CH_4	0.56
C_2H_6	0.09

Source: Siirtec Nigi

Table 2: **Amine acid gas feed to SRU**

Component	vol-%
H_2S	30.99
CO_2	58.16
N_2	10.12
CH_4	0.60
C_2H_6	0.16

Source: Siirtec Nigi

TGT operating parameters were adjusted to their normal operating figures to achieve the "ready for tail gas cut-in" status.

The thermal reactor pressure was found to be abnormally high (about 0.5 bar g) for TGT line-up due to plugging of the second and third sulphur hydraulic seals. Maintenance was consequently carried out to partially overcome the problem and the pressure was lowered to 0.32 bar g.

The recycle gas fan was shut and the TGTU was then lined-up at about 85% of nominal capacity on 22nd January 2018 in the afternoon. After operation stabilisation, the load was increased up to 100%.

The main operating parameters were monitored overnight and were stable. The average figures achieved are summarised below:

Thermal reactor pressure, bar g	0.5
Reducing reactor inlet temperature, °C	251
Max ΔT through catalytic bed, °C	11
Waste water flowrate, m³/h	170
Pumparound water flowrate, m³/h	170
Amine flowrate, m³/h	175
ΔP through water removal tower, bar	0.03
ΔP through MDEA absorber, bar	0.05
Circulating water pH	6.5
Excess hydrogen in process gas, vol-%	0.9
Residual H_2S content in treated gas from TGT, ppm vol	180

The gas temperatures at the WRT and asorber outlet were less than 40°C because the start-up was carried out in the month of January (cooling water supply temperature was less than the 32°C design figure).

The residual H_2S content in the treated gas from the absorber was checked by means of Dräger tubes due to the unavailability of the H_2S analyser. The circulating waste water quality was visually checked and was clear and free of sulphur.

It should be noted that the process gas pre-heating up to 280°C as per design could not be initially achieved initially due to improper operation of the thermal incinerator, which was found to be running at 500°C instead of 750°C.

As a consequence, the superheating of the saturated HPS generated in the Claus and incinerator waste heat boilers could not be accomplished up to the required temperature due to unavailability of sufficient flue gas sensible heat. Incorrect operation of the incinerator led to a colder superheated HPS being fed to the TGT final heater (288°C instead of 355°C) not allowing proper tail gas heating.

Instructions for keeping the incinerator temperature at minimum 650°C were given, thus allowing the tail gas to be pre-heated up to 270°C. As a result, the ΔT through the catalytic bed increased to 14°C, close to the design figure.

The TGT unit ran fairly stable at the same parameters as listed for a couple of days and the TGT start-up was considered successfully completed with full satisfaction of the client.

Salient features of HCR™ process

The HCR™ tail gas treatment process licensed by Siirtec Nigi is based on the steps previously described (hydrogenation, quench, absorption). Hence, HCR™ is quite similar to other amine-based TGT processes. Nevertheless, some benefits enhancing the plant lifetime and availability while applying the HCR™ concept can be highlighted.

The "High Claus Ratio" concept

In the HCR™ concept, the Claus unit is basically operated at a reduced combustion air/acid gas ratio when the TGTU is on stream. As a result, the H_2S/SO_2 ratio in the process gas is quite higher than the 2:1 traditional figure.

The lower sub-stoichiometric air/acid gas ratio implies a higher quantity of hydrogen generated in the thermal reactor, enough to reduce all sulphur and sulphur-bearing compounds in the Claus tail gas to H_2S in the TGT reducing reactor.

A 1-2 vol-% excess of H_2 at the WRT outlet should always be ensured. A hydrogen analyser is provided for this purpose at the outlet of the WTR.

HCR™ benefits to the Claus unit

A higher H_2S/SO_2 ratio implies a lower SO_2 content in the process gas, and less possibility to generate SO_3 as a side reaction.

As a result, the Claus catalyst lifetime is enhanced (reduced risk of poisoning due to sulphation) as well as the equipment lifetime (reduced risk of corrosion due to acid condensation in the coldest parts of the unit).

Moreover, operating the Claus unit in the "safe" zone (H_2S/SO_2 >> 2) allows higher flexibility in handling acid gas feed when its composition has high variations (fine tuning of the air demand analyser acting on the trim air flow controller in cascade mode is often a tough exercise).

HCR™ benefits to the TGTU

Lower SO_2 and sulphur species contents in the Claus tail gas allow an almost quantitative hydrogenation to H_2S in the reducing reactor. The risk of the water removal tower plugging because of SO_2 breakthrough and consequent sulphur formation in water (one of the most common problems while operating TGTUs) is therefore reduced.

There is no need for a caustic injection package, as the pH in the circulating waste water is simply controlled by acting on the H_2S/SO_2 ratio and ensuring a minimum H_2 excess in the quench gas.

The equipment life is enhanced for the same reason as mentioned above.

Hydrogen self-generation in the thermal reactor requires neither an external H_2 source nor a RGG. Incorrect operation of a RGG can lead to the risk of plugging and catalyst deactivation due to soot formation in case the required slightly sub-stoichiometric fuel gas combustion is not kept under strict control.

Low temperature activated catalysts

The use of low-temperature activated reduction catalyst is quite common nowadays and allows tail gas pre-heating to 240°C instead of 280°C as in Mellitah. HP steam generated in the Claus and incinerator waste heat boilers can be therefore be used as pre-heating medium. Consequently, there is no need for an line burner with all the related risks of soot formation as already mentioned. ■

Sulphur plant upgrade for lean acid gas processing

WorleyParsons and Linde have carried out a prefeasibility study to determine the best option to improve operations of a Saudi Aramco sulphur plant processing a lean acid gas feed containing H_2S and BTX contaminants. High level oxygen enrichment combined with acid gas enrichment unit (AGE) was found to be the most economic option. **I. Alami** and **C. Chukwunyere** of Saudi Aramco, **Dr M. Guzmann** of Linde Gas and **S. Pollitt** of WorleyParsons discuss the findings.

Global annual elemental sulphur production is estimated at over 64 million tonnes with more than 95% deriving from oil and natural gas. The most challenging feedstock for the sulphur recovery plant derives from natural gas processing which typically contains lower concentrations of hydrogen sulphide (H_2S) and often contains benzene, toluene and xylenes (BTX) which must be removed or destroyed in the reaction furnace.

Saudi Aramco has processed lean feed acid gases containing benzene, toluene and xylenes (BTX) for many years. Early operations suffered from chronic catalyst deactivation, low sulphur recovery and frequent shutdowns to replace catalyst.

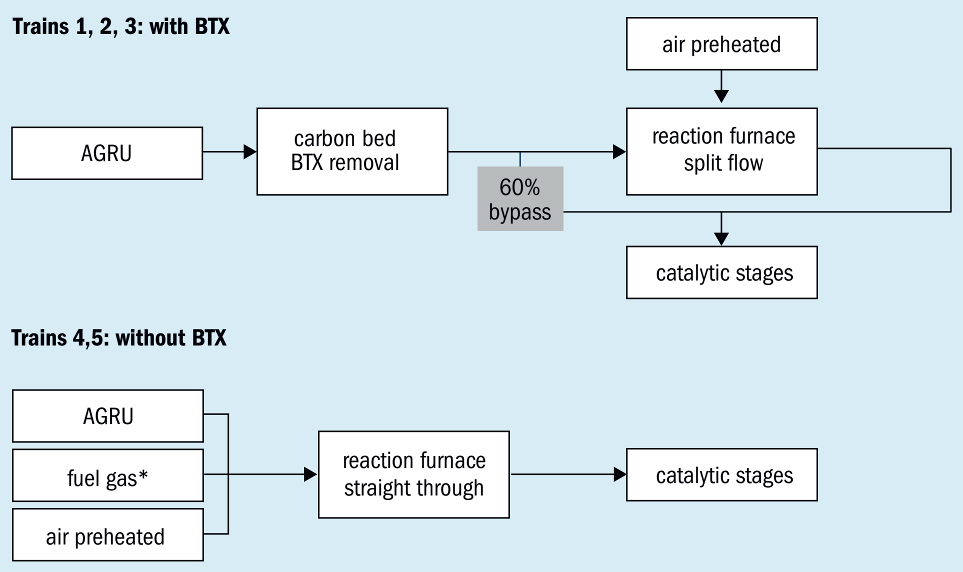
Aramco considered many options to eliminate this problem[1] including the following:

- Increasing furnace temperature to allow BTX destruction by
  - oxygen enrichment
  - fuel gas co-firing
- Removal of BTX
  - change of the upstream sour-gas treating amine
  - refrigerating the feed
  - BTX adsorption using molecular sieve
  - fuel gas stripping
  - BTX adsorption from acid gas using regenerable activated-carbon beds

Aramco showed that the carbon beds provided the most economical solution and the beds were installed at Shedgum and Uthmaniya.

This study reassesses the operation at Uthmaniya and the application of oxygen enrichment and acid gas enrichment.

Fig. 1: **Plant configuration at Uthmaniya**



*occasionally

Source: WorleyParsons/Linde

Plant configuration

The plant which forms the basis of the study is shown in Fig. 1.

There are five SRU trains (3 x 650 t/d, 2 x 700 t/d) processing a feed containing only 18% H_2S and BTX. Each consists of a Claus plant and off gas incinerator with no additional tail gas treatment.

Trains 1, 2 and 3 are fitted with carbon beds upstream of the SRU to remove BTX. Stable reaction furnace operation is achieved by by-passing 60% of the feed to the first catalytic stage which results in a high enough temperature to support a stable flame and to destroy BTX.

Trains 4 and 5 are not equipped with carbon beds as the feed gas of these units had a higher H_2S content than Trains 1, 2 and 3.

However, in order to achieve a stable flame, pre-heating of the acid gas to 230°C, pre-heating air to 330°C and occasional co-firing of fuel is required.

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

Characteristics of current operation

The operation of the carbon beds in trains 1, 2, and 3 require significant material handling operations. Bed agglomeration has also been experienced with potential carryover of BTX.

Trains 4 and 5 require significant energy input for pre-heating air and acid gas. Fuel gas co-firing must be introduced and maintained accurately to ensure a stable flame and the required reaction furnace temperature for BTX destruction.

Objectives

The study had the following objectives:

- improvement of sulphur recovery efficiency to 99.9+%;
- provision of redundancy – full processing capability must be maintained if one of the five trains is not operating;
- increased energy efficiency;
- reduced operating complexity by removing the carbon beds with the resulting reduction of operating costs.

The processing of lean acid gases can be approached using a number of technologies. This study considered two major approaches: oxygen enriched SRU technology and acid gas enrichment (AGE)

Oxygen enriched SRU technology

The standard modified Claus SRU technology uses air to provide the oxygen to convert one third of the H_2S in the acid gas feed to SO_2. This allows the Claus reaction to proceed in the furnace and in the downstream catalytic beds.

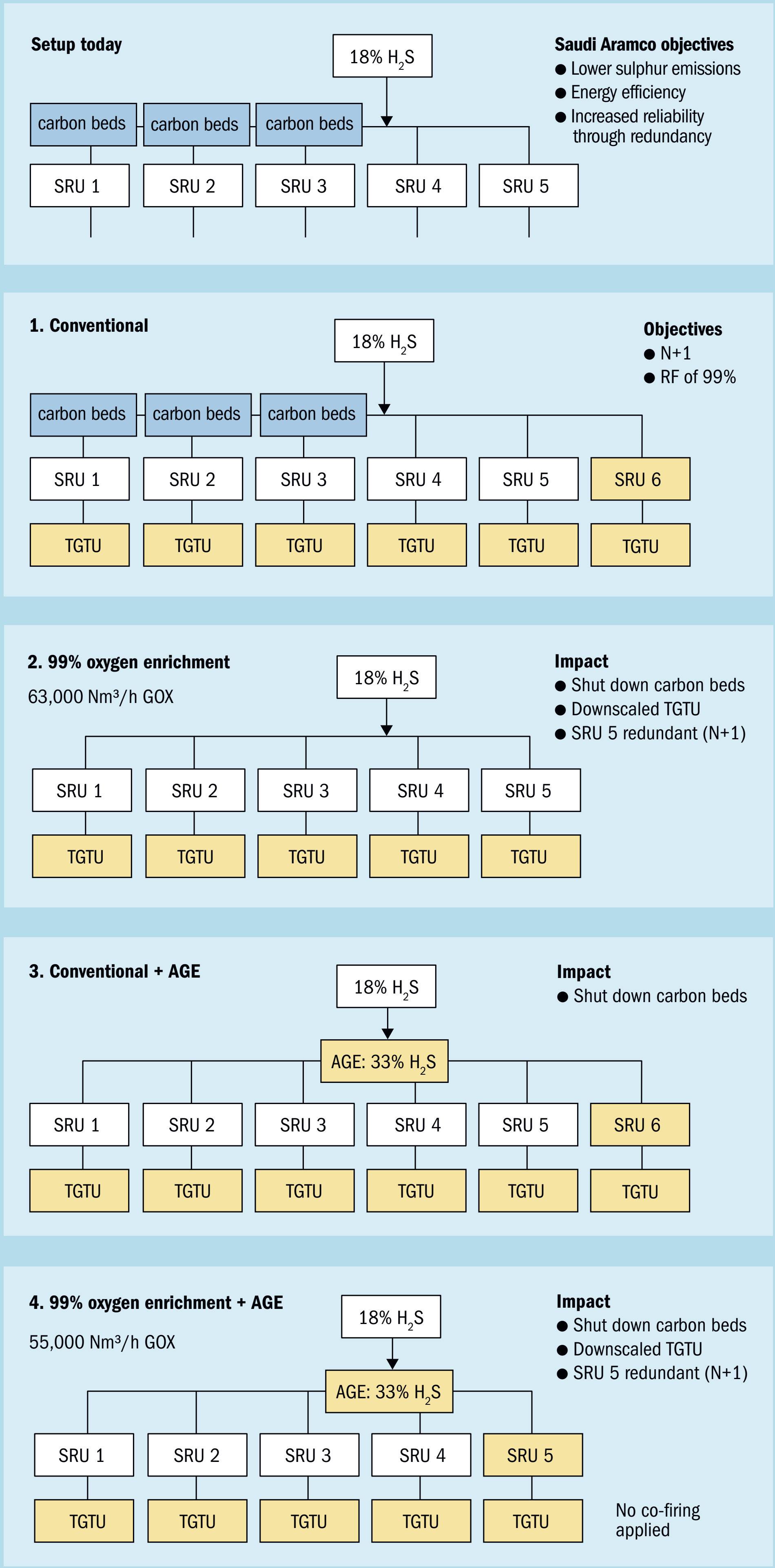
The replacement of all or some of the air with pure oxygen decreases the total volume flow through the plant due to the reduce amount of nitrogen introduced into the plant with the air. This reduced volumetric flow also allows a higher temperature to be attained in the furnace.

An earlier study[1] showed the potential for application of oxygen enrichment, particularly with lean feed gases, to lower both capital and operating costs of new plants and in retrofits.

Acid gas enrichment

Acid gas feeds containing less than about 30% H_2S pose challenges when processed in conventional Claus plants. Without further processing such feed gases will not

Fig. 2: **Process setup and improvement options**



Source: WorleyParsons/Linde

Table 1: **Capex and opex comparison**

Option	Capex (million $)	Opex (million $)	NPV (cost) (million $)
1	590	76	-1,296
2	309	86	-1,141
3	750	81	-1,487
4	469	46	-889

Source: WorleyParsons/Linde

be able to maintain a stable flame in the reaction furnace and will not achieve a high enough temperature to destroy contaminants such as BTX.

The enrichment of such streams can be carried out using a conventional amine system using a selective amine. Such an amine system can increase feed gas H_2S concentration to higher levels which can be more easily processed in the Claus furnace.

Initial concept assessment

With only 18% H_2S in the feed gas the initial assessment showed that, even with oxygen enrichment up to 99.5%, the 1,100°C temperature required for BTX destruction could not be met. A concept combining acid gas enrichment and oxygen enrichment was therefore considered in detail.

Improvement options

Fig. 2 shows the four improvement options considered.

Option 1: Conventional. Installation of Tail Gas Treating Units (hydrogenation, quench and amine units) to meet 99.9+% recovery and a 6th train to provide the required redundancy. The carbon beds remain in operation.

Option 2: Operation of all trains with air replaced by pure oxygen. In this case the redundancy can be achieved with the existing trains due to the reduced volume flow through the plants (removal of nitrogen) and the resulting debottlenecking. The TGTUs installed in each train will be physically smaller due to the removal of nitrogen with an associated reduction in operating and capital costs. Carbon beds are not needed.

Option 3: Conventional with AGE. Installation of an AGE upstream of all 5 trains increased the H_2S concentration in the feed gas from 18% to approximately 33%. The addition of a 6th train provides redundancy and TGTUs achieve the required recovery. The carbon beds do not need to operate in this case as the increased H_2S concentration allows a high temperature to be reached in the furnace.

Option 4: Oxygen enrichment and AGE with TGTUs. This option provides redundancy without the need for a sixth train. The removal of nitrogen due to 99.9% oxygen enrichment and the removal of CO_2 in the AGE results in a further reduction in the volumetric throughput and size of each TGTU.

Results

The capital and operating costs were calculated for each of the four options listed is shown in Table 1.

Option 1: This conventional air-based approach requires a large capital investment for a sixth train and six TGTUs. All items of new equipment are large due to the large volumes of air (nitrogen) and co-fired gas products which need to be handled. The carbon beds are still in operation with the associated operating and maintenance costs.

Option 2: Using a high level of oxygen enrichment reduces the capital cost by $280 million due to the elimination of sixth train – the redundancy can be achieved with the existing five trains. The new TGTUs will handle lower gas volumes due to the removal of nitrogen. Both result in lower capital cost compared with Option 1. Elimination of the carbon beds reduces operating and maintenance costs, but overall operating cost is increased due to the cost of oxygen.

Option 3: The installation of an AGE adds considerably to the capital cost of the required modifications – $160 million more than Option 1. This is due to the cost of the AGE and the addition of a sixth SRU train and six TGTUs. Operating costs are similar to Options 1 and 2.

Option 4: The additional capital cost of the AGE is offset by the elimination of the sixth train and the smaller physical size of the five TGTUs. Operating costs of this option are the lowest of the four cases considered due to the elimination of the carbon beds, the lower volumes of gas processed, avoidance of co-firing and the smaller size of the TGTUs.

Use of oxygen when processing hydrocarbons

Oxygen enrichment in SRUs is well proven and there are over 100 references worldwide. Oxygen is also safely used in the petrochemical industry e.g. in the production of ethylene oxide and generally in gasification processes. Like all components encountered in the processing of acid gases (H_2S, SO_2, CO_2) oxygen presents hazards. However, these hazards are well understood and mitigation measures are well established to provide safe and reliable operations and application in SRUs. In the approach described herein the provision of oxygen is considered to be by a third party i.e. oxygen is considered as a utility and is accounted for as purely an operating cost.

Conclusions

The benefits of using oxygen enriched SRUs when handling lean acid gases has been confirmed.

- For very lean acid gases oxygen enrichment alone will not result in furnace temperatures high enough to destroy BTX.
- When handling very lean acid gas the combined use of AGE and oxygen enrichment has been shown to be the best economic option.

In this case the line-up of AGE, Claus and TGTU with oxygen enrichment met the criteria set out in the project scope:

- minimised equipment modifications;
- provides redundancy;
- reduces CO_2 footprint due to the elimination of fuel gas co-firing;
- enables shutdown of carbon beds.

This was shown to be possible at the lowest capital and operating costs – showing a lifecycle cost benefit over 20 years at 5.6% discount rate of almost $410 million. ■

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1. Crevier, Al-Haji, Alami: "Evaluating solutions to BTX deactivation of claus catalyst in lean feed SRUs, Brimstone Engineering, Vail Sulphur Symposium, September 9-13, 2002.
2. "Oxygen enrichment in sulphur plants to reduce the life cycle costs of new-build, large gas plants", ADIPEC 2016. SPE 183406.

Integrated AGE and hydrocarbon removal in sour gas processing

A new sour gas treating scheme comprising H_2S removal, separation of impurities such as hydrocarbons, BTEX and mercaptans, and an integrated acid gas enrichment system has been developed for sour gas field developments, refineries, associated gas, shale gas, syngas from power plants, natural gas processing applications, and early production facilities. **M. Rameshni** and **S. Santo** of Rameshni & Associates Technology & Engineering (RATE) describe this innovative scheme named Enrich-MAX.

Increasing energy costs and the growing demand for natural gas have driven the development of sour gas fields around the world. About 40% of the world's natural gas reserves are in the form of sour gas where H_2S and CO_2 compositions exceed 10 vol-% of the raw acid gas produced. In some cases the acid gas composition in these reserves is very high and the economics of producing pipeline quality gas are marginal. Natural gas almost always contains contaminants or other unacceptable components which must be removed when conditioning natural gas for pipeline LNG or GTL, LPG and condensate or marine fuels.

Emissions regulations are getting tighter and there is increasing demand to achieve higher sulphur removal and recovery. To comply with progressively tighter product purity specifications and stricter environmental regulations, while at the same time handling feedstocks from more diverse and sometimes lower-grade sources, gas treatment plant operators in the hydrocarbon processing industries are having to adopt measures to deal specifically with minor impurities which would otherwise impair the efficiency of the main gas treatment unit or cause violations of environmental emission standards.

Fig. 1: **Main absorber system**

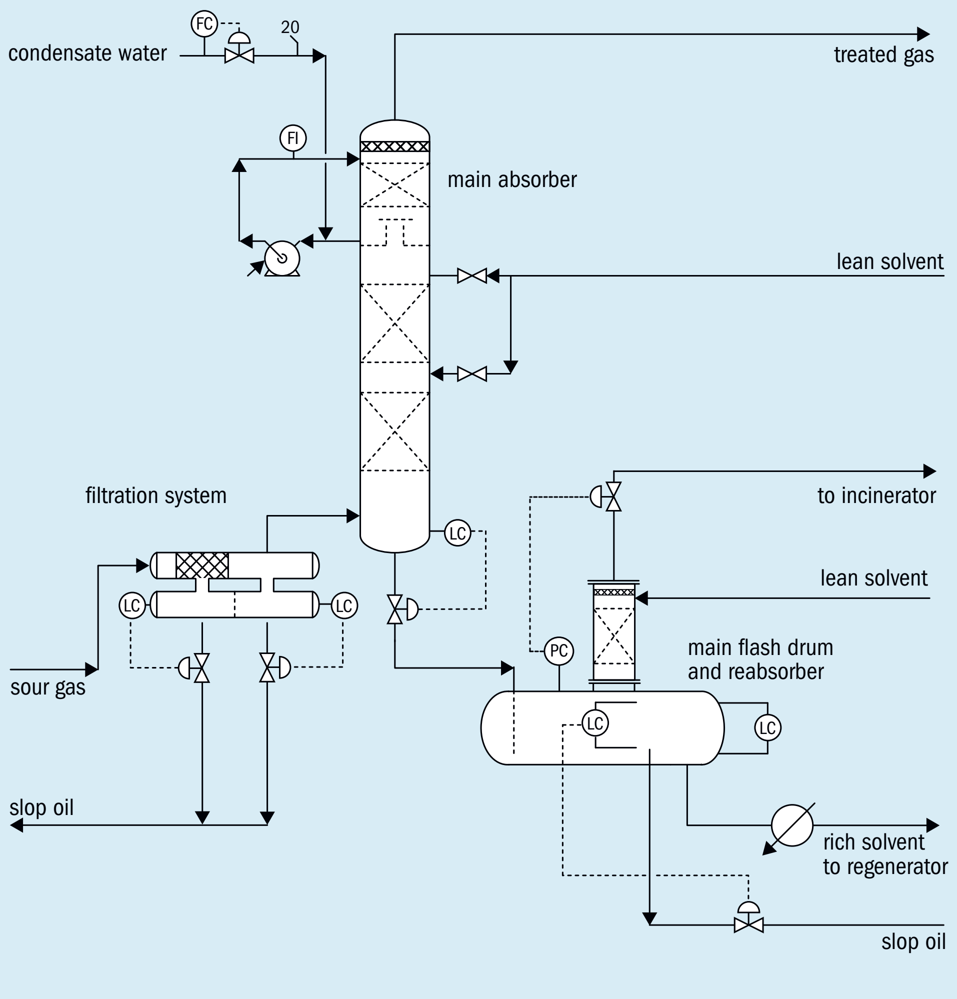

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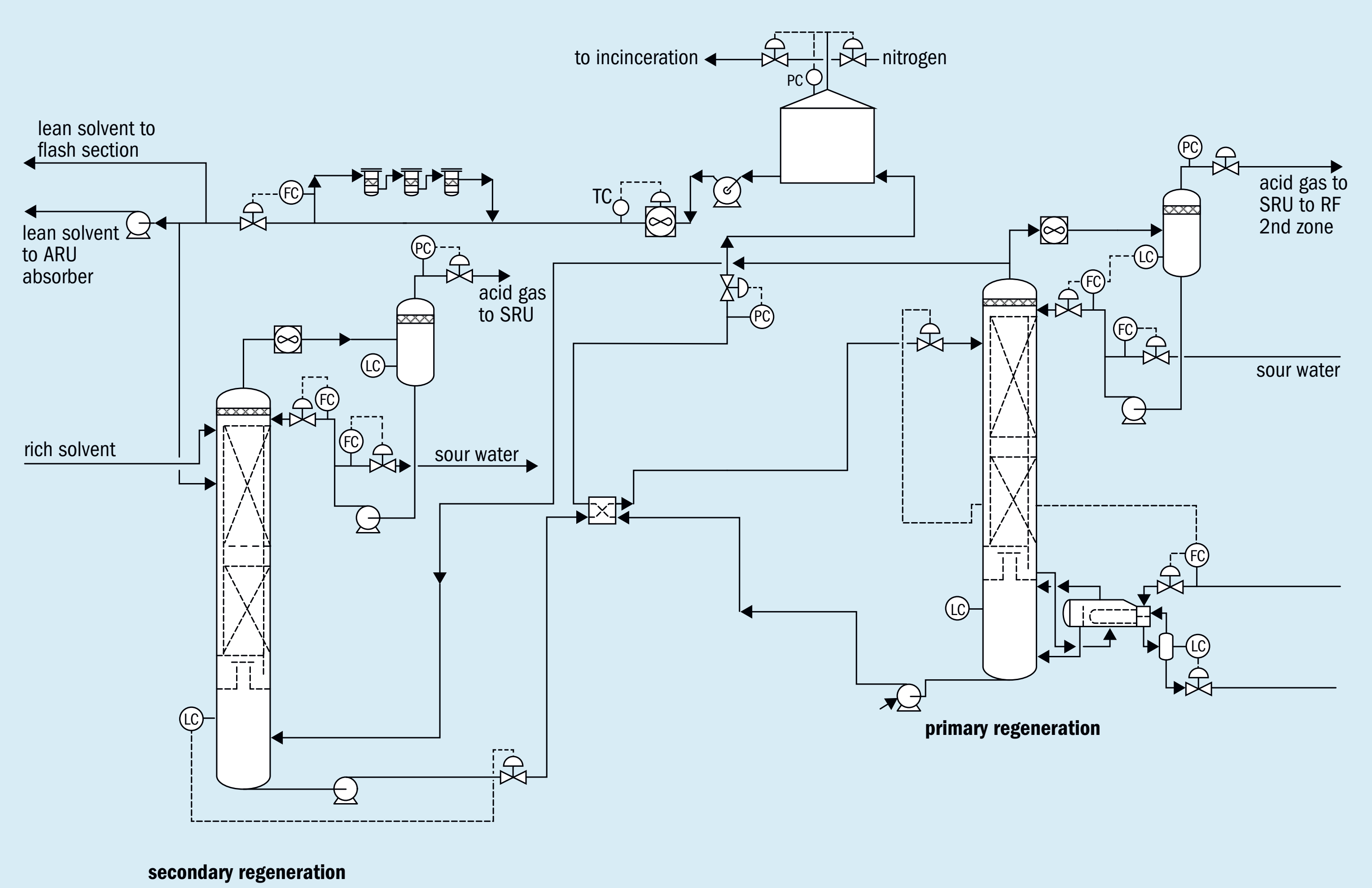
Fig. 2: **Primary and secondary regeneration system**



Source: RATE

These impurities include elemental sulphur, mercury, heavy hydrocarbons, ammonia, carbon sulphides and mercaptans, and sub-micron particulate solids such as ferrous sulphide. Traditionally, depending on their nature and the set-up of the processing plant, these impurities have been dealt with by preliminary treatment upstream of the main gas processing unit or by final conditioning of the treated gas.

Enrich-MAX

In response to recent feedback from customers, RATE has developed an innovative sour gas treating configuration, named Enrich-MAX for the processing of lean H_2S acid gas streams which contain high levels of hydrocarbons and mercaptans. These feed compositions are challenging to treat and make it difficult to establish stable operation in a typical sulphur recovery unit (SRU). One unit has already been modified with this technology and several other proposals have been submitted. The technology is patent pending with the United States patent office.

Detailed description

In the Enrich-MAX sour gas treating configuration, sour gas stream is filtered and flows to the absorber, where lean solvent is used counter current to the sour gas stream. The overhead of the absorber is sent to the treated gas header, while the rich solvent flows from the bottom of the absorber to the flash drum.

Fig. 1 represents the filtration, main absorber, flash drum and re-absorber system.

The rich solvent drum is a horizontal vessel equipped with a packed scrubber on the top. Flash gas from the solvent flash drum is contacted with lean solvent to strip the hydrocarbons and is then sent to the incinerator.

The rich solvent, which contains high levels of H_2S and CO_2, is sent to a flash drum where the hydrocarbons are removed by the reduction in pressure. Some H_2S and CO_2 are also removed in the flash drum. The flash gas, containing primarily hydrocarbons, is used to fuel the incinerator.

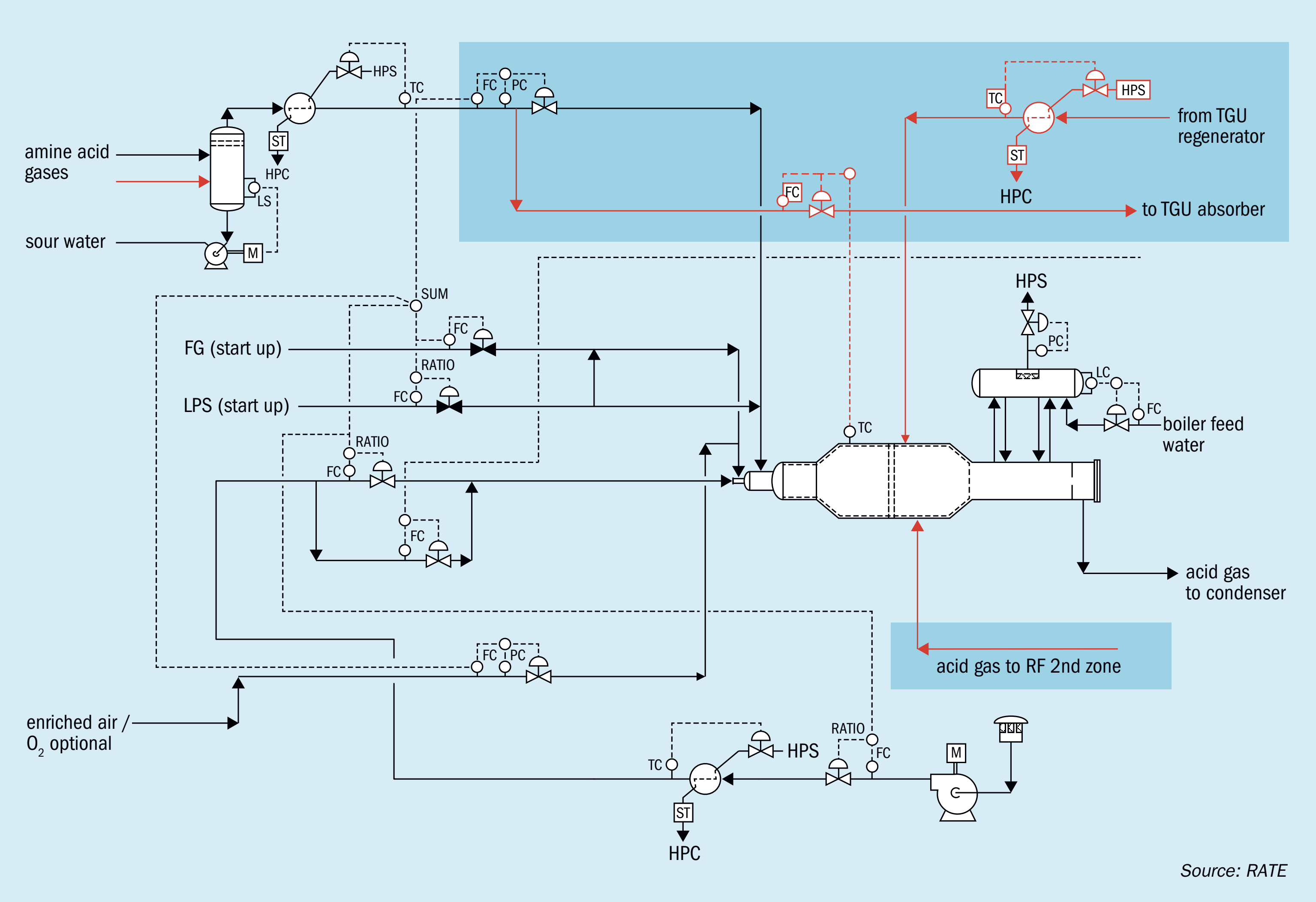
The rich solvent is on flow control reset by the level in the flash drum. The rich solvent from the flash drum is cooled indirectly with cooling water, or any type of cooler, to separate the hydrocarbons and mercaptans before entering the secondary regenerator.

The secondary regenerator in the acid gas removal section is the unique configuration of this invention. It is a packed tower, or tower with trays, equipped with a condenser overhead without any reboiler or steam injection. The secondary regenerator enhances the removal of hydrocarbons and improves acid gas enrichment. It allows the acid gas to the sulphur recovery unit to be divided into two streams with only one stream containing hydrocarbons and mercaptans.

The secondary regenerator receives three feed streams:

- cooled rich solvent from the flash drum;
- cooled lean solvent from the primary regenerator;
- a slip stream of the overhead acid gas from the primary regenerator.

Fig. 3: **Configuration of SRU reaction furnace two-zone design**



Source: RATE

The remaining acid gas from the primary regenerator flows to the primary overhead condenser, and then to the sulphur recovery unit.

Fig. 2 represents the primary and secondary regeneration system.

The secondary regenerator performs two functions:

- to further enrich the acid gas from the primary regenerator;
- to separate the hydrocarbons, mercaptans and BTEX.

The primary regenerator overhead stream is hot and in order to improve the separation of hydrocarbons the rich solvent is cooled before entering the secondary regenerator. The secondary regenerator overhead gas stream containing the rich H_2S, hydrocarbons, and mercaptans flows to the first zone of the reaction furnace in the sulphur recovery unit (SRU). Alternatively, the acid gas overhead from the secondary regenerator can be directed to the quench system in the tail gas treating system, where the hydrocarbons can be recovered and used as fuel.

The SRU reaction furnace has a unique two-zone design, where each zone can receive multiple streams. Fig. 3 represents the unique configuration of the two-zone reaction furnace in the sulphur recovery unit. The scheme can be designed and operated with air and oxygen.

The acid gas from the secondary regenerator containing the hydrocarbons, mercaptans and H_2S flows to the first zone of the SRU reaction furnace, where the combustion temperature is higher than the second zone and is sufficiently high to destruct the hydrocarbons. The acid gas from the primary regenerator flows to the second zone of the reaction furnace where the combustion temperature is lower but since it is free of hydrocarbons, soot formation and catalyst deactivation is eliminated.

In a conventional sulphur plant, the acid gas from the H_2S removal comes from one regenerator and for lean gas application if the acid gas is split between two zones of the reaction furnace, the formation of soot can occur and deactivate the Claus catalyst which will also reduce the overall sulphur recovery.

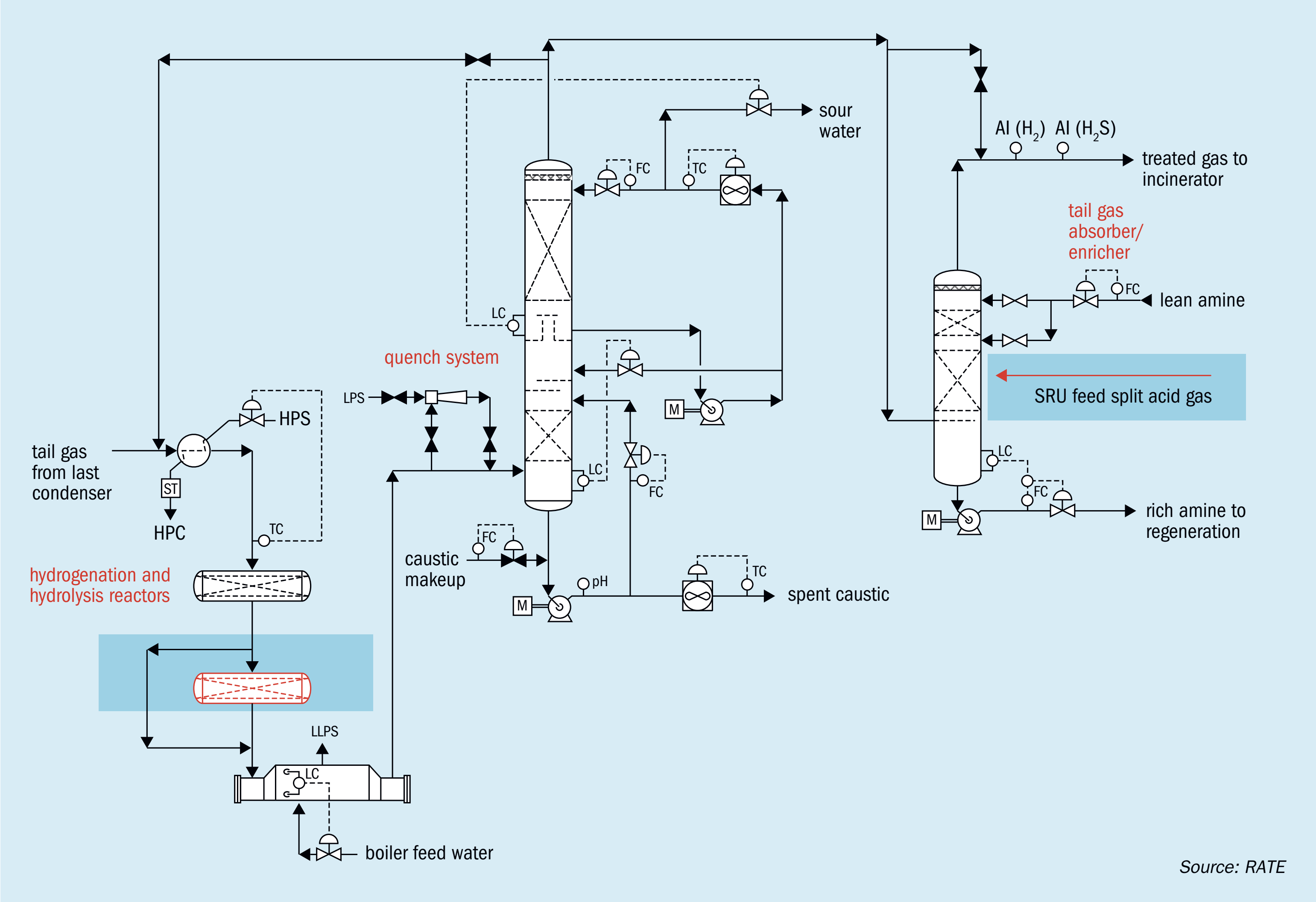
The bottom stream of the secondary regenerator contains the rich solvent and flows via the bottom pump to the lean/rich heat exchanger, where it is heated up before entering the primary regenerator tower. The lean solvent from the primary regenerator is cooled in the lean/rich exchanger and goes to the secondary regenerator.

In the tail gas treating unit, an additional hydrolysis reactor is located after the hydrogenation reactor and contains suitable Claus catalyst to achieve near 100% hydrolysis of COS, CS_2 and any sulphur compounds, and the hydrogenation reactor consists of regular or low temperature hydrogenation catalyst as knows as CoMo catalyst.

Fig. 4 represents the tail gas treating system with the hydrolysis reactor and partial enrichment tail gas absorber system. Fig. 5 represents the tail gas regeneration system recycling the acid gas to the reaction furnace.

The hydrolysis reactor is added because, over time, the tail gas hydrogenation catalyst loses its efficiency which reduces the

Fig. 4: **Tail gas treating system**



Source: RATE

performance of the unit. The hydrolysis of COS and CS_2 decreases, resulting in increased SO_2 emissions. Since the feed gas composition to the SRU is not rich in H_2S, one of the byproducts from the reaction furnace is COS.

Even though titanium catalyst is used for COS/CS_2 hydrolysis in the first SRU reactor, operating data from similar applications show significant COS in the tail gas stream. It is known that the CoMo hydrogenation catalyst hydrolyses COS but operating data and experience indicate significant COS from the hydrogenation reactor outlet, e.g. 30-40 ppmv at equilibrium condition. Therefore, the hydrolysis reactor is needed to assure that all of the sulphur species are hydrolysed.

The tail gas absorber can also operate as a partial acid gas enrichment unit and receives two acid gas streams, the quench system overhead and a slip stream of the amine acid gas that flows to the sulphur recovery unit.

If the catalytic stages of the sulphur recovery unit consist of sub dew point, direct oxidation and reduction processes, then instead of tail of tail gas treating, caustic scrubbing or RATE's Super Enhanced Tail Gas Recovery (SETR) process can be applied to achieve 99.9% recovery.

The acid gas from the amine unit to the sulphur recovery unit is split with up to 75% of the amine gas entering the first zone of the reaction furnace and up to 25% of the acid gas being routed to the tail gas absorber in addition to the quench overhead stream that normally flows to the tail gas absorber (i.e. the tail gas absorber receives two streams). The tail gas amine unit is designed with a much higher amine loading similar to the amine unit. In summary:

- 25% of the amine acid gas is sent to the tail gas absorber;
- 75% of the amine acid gas is sent to the first zone of the reaction furnace;
- the tail gas absorber operates at higher rich H_2S loading (0.2-0.3 mol/mol);
- the tail gas recycle from the tail gas regeneration unit is also recycled to the SRU but not to the first zone of the reaction furnace. Instead, the acid gas from the tail gas regeneration column, which is free from hydrocarbons and mercaptans, is preheated and recycled back to the second zone of the reaction furnace.

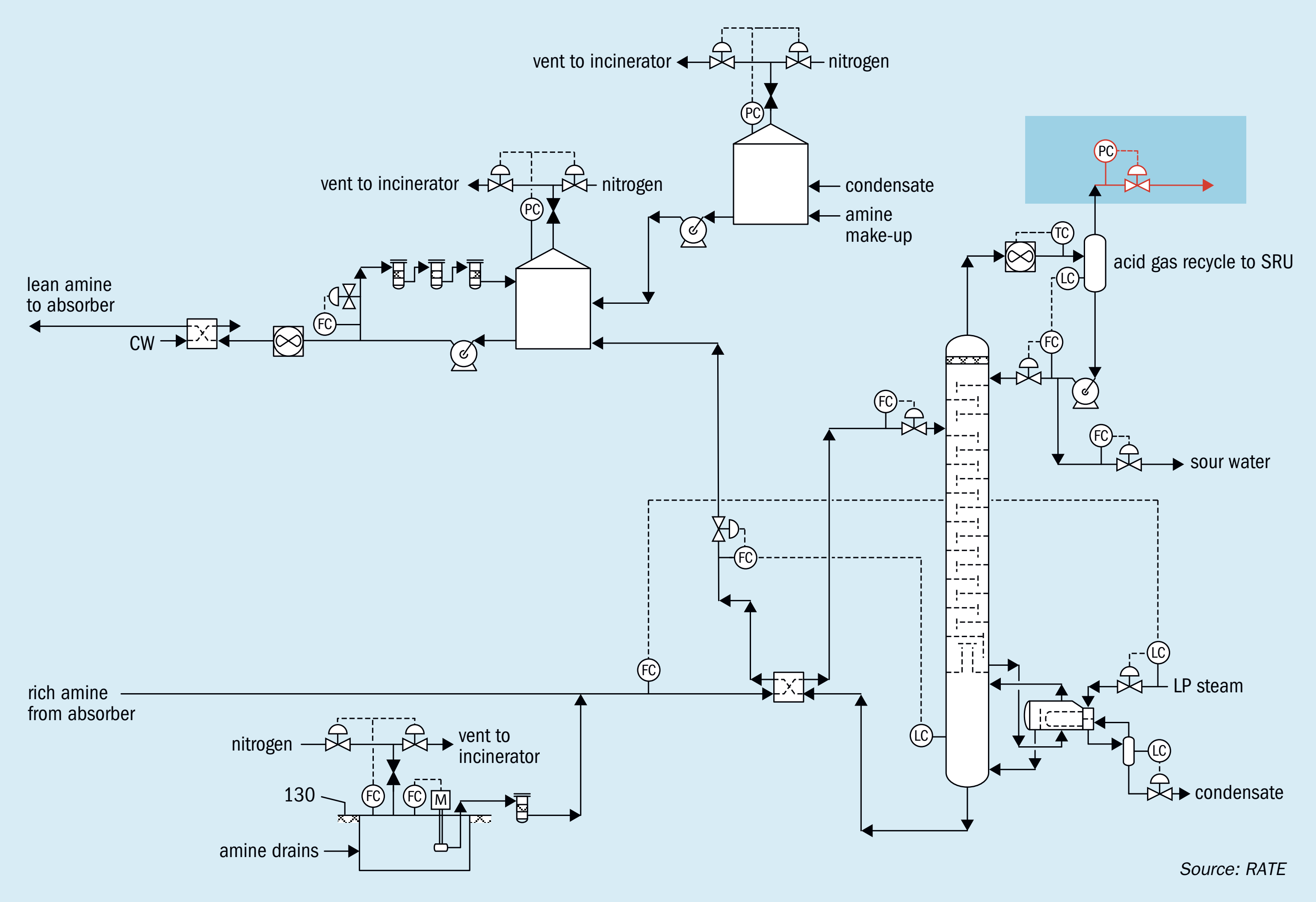
The partial acid gas enrichment results in improved sulphur recovery and reduces costs compared to a conventional tail gas treating design.

The overall scheme is optimised on a case by case basis, according to the acid feed gas composition.

The tail gas absorber receives the partial acid gas entering the sulphur recovery and will have partial enriched in the tail gas absorber as the partial acid gas enrichment absorber.

The advantages of the new invention is the stream containing the hydrocarbons, mercaptans and BTEX is destructed in the first zone where the combustion temperature is higher, which eliminates soot formation and catalyst deactivation, improves the sulphur recovery efficiency and increases the reliability of operation with lean gases. In addition it is cost saving for eliminating the acid gas enrichment, and hydrocarbon removal units. Another

Fig. 5: **Tail gas regeneration system**



advantage of the new invention is the feed stream to the sulphur recovery unit is split compare to the conventional method even if acid gas enrichment unit employed as a separate unit the feed to the sulphur recovery remains as one stream.

A broad range of aqueous ethanolamine solutions used in the refinery and natural gas industries for removal of H_2S and CO_2 and other components and impurities. Ethanolamines are weak bases and absorb acid gases, such as H_2S and CO_2, by an acid-base reaction. In practice, the acid gases are first physically dissolved in the amine solution and then react with the amine by the reactions shown below:

MDEA – H_2S

$$2R_2NCH_3 + H_2S \rightleftharpoons (R_2NHCH_3)_2S$$
MDEA-sulphide

$$(R_2NHCH_3)_2S + H_2S \rightleftharpoons {}_2R_2NHCH_3HS$$
MDEA-bisulphide

MDEA – CO_2

$$2R_2NCH_3 + H_2O + CO_2 \rightleftharpoons (R_2NHCH_3)_2CO_3$$
MDEA-carbonate

$$(R_2NHCH_3)_2CO_3 + H_2O + CO_2 \rightleftharpoons 2R_2NHCH_3HCO_3$$
MDEA-bicarbonate

Where R = ethanol radical ($-CH_2-CH_2OH$)

In absorption, the reactions proceed to the right exothermically and the equilibrium is favoured by low temperatures and high acid gas partial pressures. The partial pressure is the total pressure multiplied by the mole (or volume) fraction of the acid gas component. The optimum temperature for absorption is about 35°C because the increasing viscosity of the solution will decrease the absorption efficiency at lower temperatures.

In regeneration, the reactions proceed to the left and are favoured by high temperatures and low acid gas partial pressures. The maximum temperature for regeneration is about 130°C because the solvent will degrade at higher temperatures.

In addition, for removing other impurities, such as mercaptans, different types of well-known additives can be added to the generic solvents to improve the absorption. These solvents are so-called selective solvents.

Conclusions

This scheme consists of two regenerators in the main amine unit, special design of the two-zone reaction furnace to receive multiple gas streams and provide stable and reliable operation of the sulphur recovery unit, the addition of a hydrolysis reactor after the hydrogenation reactor, and a tail gas absorber designed for partial enrichment to allows the handling of hydrocarbon impurities from sour gas field developments where H_2S is not rich enough to establish stable operation. This configuration eliminates standalone acid gas enrichment, eliminates expensive chillers in hot climates e.g. in the Middle East region, and reduces high energy consumption for the chillers. Overall, it achieves more reliable operation, lower capital and operating costs, higher recovery and even lower SO_2 emissions. In addition, in some cases, proprietary amine solvents can be eliminated and generic solvents can be used to meet project specifications.

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