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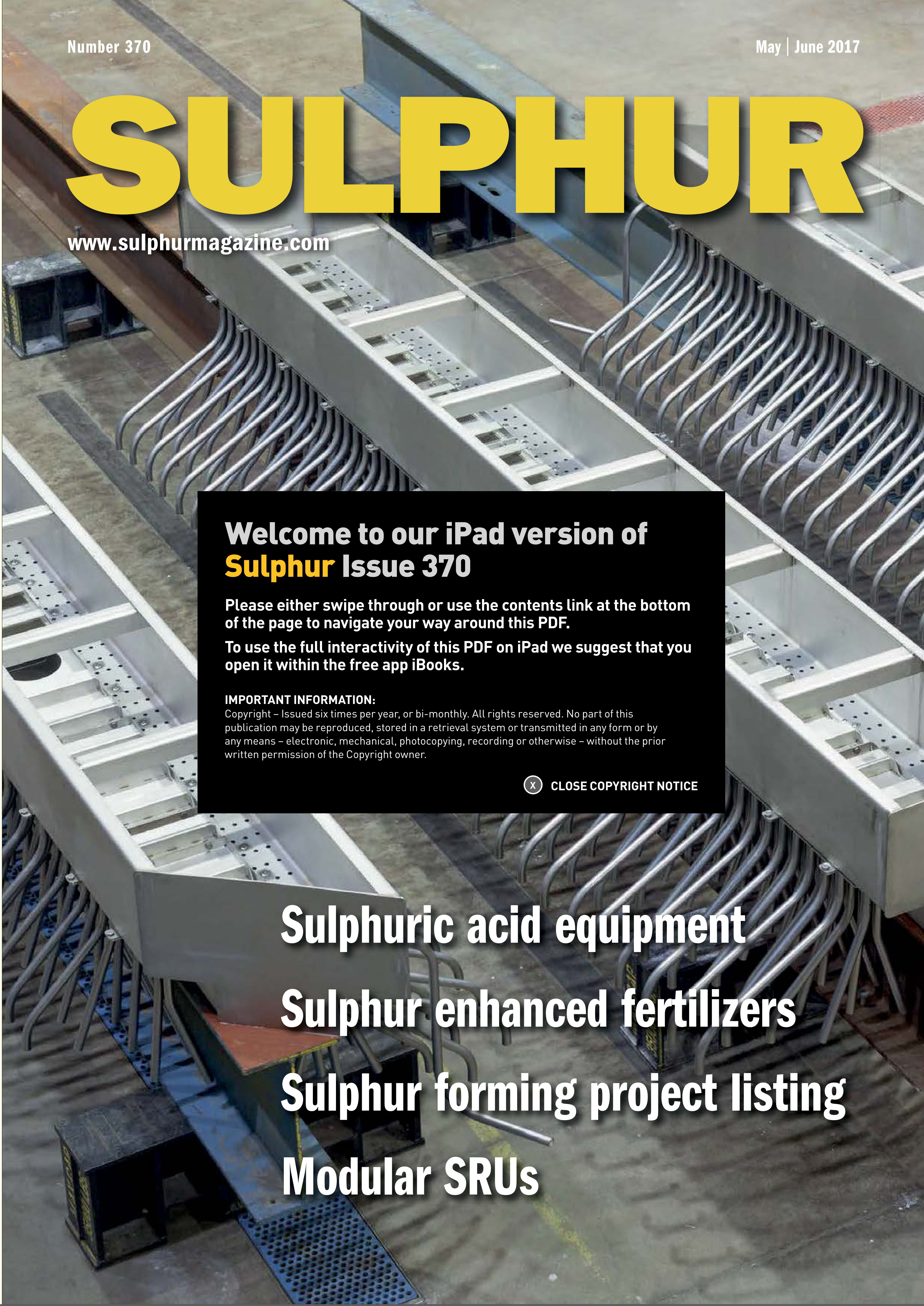

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Sulphuric acid equipment

Sulphur enhanced fertilizers

Sulphur forming project listing

Modular SRUs

Cover: Chemetics ISO-FLOW™ Sulphuric Acid Trough Distributor with SWIFT-LOCK™.
Adolfo Fernandez / Chemetics

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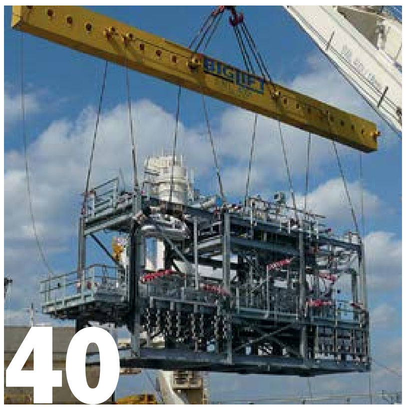
Sulphur fertilizers

A new range of sulphur enhanced fertilizers are filling the need for S as a nutrient.



Modular SRUs

The benefits of modular construction.

Read this issue online at: www.sulphurmagazine.com

Published by:
BCInsight

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Diesel: friend or foe?

It's not easy being a refiner. Changing regulations and changing tastes in fuel consumption present an ever-changing set of goalposts to try and shoot for. Balancing emissions of carbon dioxide and sulphur dioxide, fuel slates and yet still finding money to pay for new investment is a constant challenge. For European refiners, the steady move towards diesel passenger cars has led to an overhang of gasoline capacity which historically has been exported to the US, but rising domestic capacity and increasingly fuel efficient vehicles in the US have seen those imports more than halve over the past decade. But even as refiners have consequently moved to try and boost their output of diesel, so diesel as a fuel for road vehicles has started to come under increasing scrutiny in Europe and elsewhere. Diesel cars emit tiny particles of soot and nitrous oxides which are an inevitable consequence of the higher pressure and temperature used to generate spontaneous fuel ignition in a diesel engine, and car makers' claims to have found a way around this have been demonstrated as hollow in a series of scandals involving cheating on government emissions tests in the US and Europe. Now there is increasing pressure on local and national authorities to crack down on use of diesel vehicles in cities; Paris, Madrid, Athens and Mexico City have all vowed to outlaw diesel vehicles by 2020. The UK is considering tax penalties and cash back for early scrapping of vehicles. New diesel registrations in Europe have fallen from 57% of all vehicles in 2012 to 47% today and will continue to fall, and with it diesel consumption.

> **Refiners have little incentive to invest in new low sulphur fuel capacity until demand drives prices upwards.**

But nor is it an easy time to be a ship owner. January 1st 2020 will see the introduction of the International Maritime Organisation's 0.5% global cap on sulphur in marine fuels, down from the current allowance of 3.5%. This is another headache for refiners, who will no longer be able to sell high sulphur fuel oil (HSFO), and who will have to find another way to deal with bottom of the barrel fractions, probably recovering a couple million more tonnes per annum of sulphur in the process. But it is a bigger headache for ship owners, who face up to $60 billion per year of extra costs, according to analysts Wood Mackenzie. At a recent bunker fuel conference in Fujairah, UAE, the world's second largest port for bunkering, there was considerable concern expressed over where this might be leading – refiners have little incentive to invest in new low sulphur fuel capacity until demand drives prices upwards, but this will not happen until after the changeover. Investing in alternative scrubbing technology is expensive and difficult to justify in advance of the deadline, and makes most sense for larger vessels, which benefit from economies of scale. Alternative fuels like LNG and methanol may make some inroads, but probably only at the fringes until there is a sustained price difference for low sulphur marine diesel oil (MDO). Given a large-scale shortage of MDO post-2020, Wood Mackenzie forecasts initial compliance rates of only 70% with the new regulations, and suggests there may be a need for some kind of transitional arrangement.

Refiners' strategies for dealing with this looming cliff are likely to be as varied as their refinery compositions and product slates; some refiners are looking at ways to create 0.5% sulphur products from existing product streams, via blending, while others are examining ways to desulphurise HSFO. But one possible silver lining could come from a continuing decline in consumption of road diesel. Marine diesel oil is generally a blend of residual, heavy fuel oil with marine gasoil (MGO), and marine gasoil is a distillate fraction the majority of which is essentially diesel fuel. Most projections have tended to blithely assume that diesel road fuel consumption will continue to increase, but it fell last year in China, Europe and North America, and there is a perceptible sense that the tide is turning against diesel because of the associated particulate matter and NOx pollution. If that drive to eliminate diesel on land gathers pace, there might be more available for use at sea – marine fuels represent only about 10% of all fuel use – it would only take a 10% fall in road diesel consumption for sufficient spare capacity to be available to replace nearly half of all maritime fuel consumption. Diesel production may turn out to have not been such a poor investment after all. ■

Richard Hands, Editor

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Price trends

MARKET INSIGHT

Meena Chauhan, Research Manager, Integer Research (in partnership with ICIS) assesses price trends and the market outlook for sulphur.

SULPHUR

Price momentum stalls

The upward trend in global sulphur pricing appeared to reach a ceiling in April as sentiment waned and producers could not sustain the ongoing bullish momentum. Ultimately, the 42% rise in sulphur prices between August 2016-March 2017 was not matched by end product pricing in downstream markets such as processed phosphates and a downward correction was expected. Sulphur supply availability is not expected to see significant change through the second quarter of 2017, but the second half of the year is likely to see a shift based on the new projects due to come online. Additional export capacity from the Kashagan project in Kazakhstan and RasGas' Barzan project in Qatar could lead to downward pressure later in the year – should both projects ramp up as planned.

Middle East producer pricing for April saw a drop – following the increases posted for March. Adnoc announced a price of $88/t f.o.b. Ruwais for the Indian market for April, down by $6/t on March levels. In Qatar, Tasweeq posted its prices at $83/t f.o.b. Ras Laffan, down by $10/t month on month. Over in Saudi Arabia, Aramco Trading also announced a $9/t decreases for April, at $85/t f.o.b. Jubail. Expectations looking ahead to the remainder of the second quarter are for rollovers or further slight decreases – based on the lack of support from downstream markets.

Hesitation had been seen in March from major market China to accept prices above $100/t c.fr. Some buyers also made a move to to local supply sources, instead of the import market in April – indicated by the dip in inventories to 1.3 million tonnes at the major ports in China. As export price levels dropped from suppliers in the Middle East – interest in import volumes may see a boost, leading to a potential uptick in inventory levels. Spot prices in China dropped back into the $90s/t c.fr. at the end of March and into April, down from highs of around $110/t c.fr. just a few weeks earlier. Imports to China in January-February show a drop year on year, down by 13% to 1.9 million tonnes, reflecting a weaker start to the year. However, trade from Saudi Arabia showed a 29% boost to over 500,000 tonnes. Imports from the UAE, Iran, South Korea and Canada also reflected increases. Meanwhile erosion was seen from Japan, Qatar, Russia and India. Based on projected growth in China's domestic sulphur production in 2017 of around 18%, we would expect to see a slight drop in imports through the year compared to 2016.

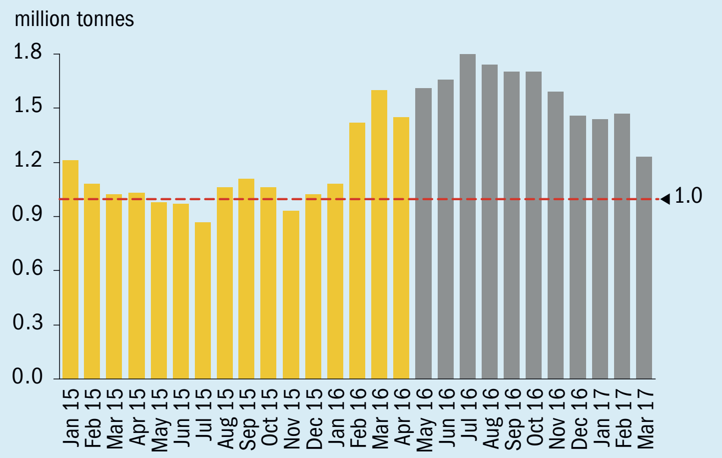
Sulphur production stalled at Syncrude's Mildred Lake upgrader facility in Alberta, Canada in March following an explosion and fire. Initial estimates were for the outage to last several weeks, temporarily tightening sulphur availability. Despite this, Vancouver spot prices came under pressure, in line with international developments moving into April. The range softened into the mid/high-$80s/t f.o.b., a drop from the peak of around $93/t f.o.b. in March. Meanwhile in the US, sulphur production has been stable, following the recovery seen in 2016. In January 2017 totalled 760,000 tonnes, largely unchanged on a year earlier but below levels in December 2016. Exports from the US Gulf have been firm, with February shipments up by 65% year on year to over 213,000 tonnes. This trend is expected to continue, with exports to Brazil to remain the leading market.

In the US, PotashCorp (PCS) was heard settling its Q2 sulphur contracts in Tampa down by $5/long ton, bringing the price to $70/long ton DEL (delivered).

Following the drop in Brazilian sulphur imports in 2016 (down 7% at just 1.8 million tonnes) we expected to see some recovery in the new year. Import data for Q1 2017 show a 53% rise year on year to around 615,000 tonnes – also eclipsing imports in the same period in 2015. A significant boost has been seen in trade from the US, rising 20% to 253 ,000 tonnes during Q1. Sulphur sourced from the UAE has also grown, up by 57% to 119,000 tonnes – in line with the rise in exports from the UAE. Volumes from Russia have began to recover this year to

Fig 1: Chinese sulphur port inventory, Jan 2015 to Mar 2017

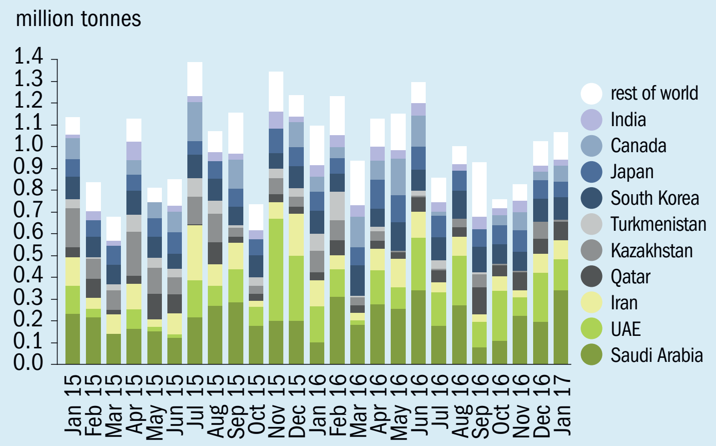
Sulphur stocks at the nine key China ports continued to erode as expected and have dropped to 1.2 million tonnes in March. Traders and end users liquidated stocks in light of high import prices for sulphur. The recent downturn may encourage purchasing and stocks to rise.



Source: Integer, ICIS

Fig 2: China monthly sulphur imports, Jan 2015 to 2017

China sulphur imports from the UAE gained significant ground in 2016, growing by 18% year-on-year when compared with 2015. The UAE led trade to China in December 2016, at over 220,000 tonnes, but in January 2017 volumes dropped to 139,000, down 15% year-on-year.



Source: Integer, GTIS

date, following the drop in 2016. Q1 imports were at 80,500 tonnes. Prices remained in the low-$100s/t c.fr. but were expected to drop below this level from April in line with the drop in export prices from key supply regions.

Lower prices in the Middle East and China have also trended through to the Indian spot market, down into the $90s/t c.fr. in April. The recent slowdown in interest for cargoes to India came on the back of maintenance turnarounds at major consumers during the first quarter. IFFCO may return to the market from April. Sulphur consumer FACT started its planned maintenance in early April at its processed phosphates facility in Cochin, set to last 40 days. PPL was also expected to begin a month long maintenance at Paradip during April. The turnarounds in the region are expected to slow down interest in spot volumes. Meanwhile, Coromandel resumed its operations, also in the aftermath of a one month turnaround in March.

SULPHURIC ACID

Markets firm

Global sulphuric acid prices have been firming through into the second quarter of the year, buoyed by pockets of tightness and stable demand. Benchmark European export prices rose to $17/t f.o.b. on the high end in April, reflecting business in Brazil and the US. The smelter turnaround schedule during Q2 continue to aid in the more balanced supply outlook. Producers Atlantic Copper and Boliden are set to hold turnarounds while Kemira is also expected to conduct works in the coming months. Exports from Huelva will see a slowdown through May on the back of Atlantic Copper's shutdown.

Acid prices in Chile saw a significant boost in Q2, on the back of a temporary supply shortage, with spot levels rising to over double the level of contracts set for 2017, to over $60/t c.fr. Copper producer Codelco completed its heavy maintenance schedule and was due to return to regular production and contract deliveries. A strike at the Chiquicamata smelter on 12 April was also announced, with the full impact on operations to be determined. Acid supply from Peru has also impacted Chile prices. A strike was underway in mid April at Southern Copper's Ilo smelter as well as its mines. The Cajamarquilla zinc smelter resumed operations in April following its force majeure declaration on its sulphuric acid deliveries in March. Production levels were only heard at around 50% of capacity however.

The tight supply/demand balance and a more positive sentiment has led to increased prices for exports from South Korea and Japan, rising out of negative netbacks into double digits. The primary driver has been major producers LS Nikko and Korea Zinc being out of the spot market, focussing on contract commitments. Korea Zinc underwent unplanned maintenance on one of its lines on 17 March, set to last for one month and leading to a loss of 15,000 tonnes of acid. The producer is also heard to be planning a maintenance for May, with initial estimates from industry sources 20,000 tonnes of acid would be lost. Demand and enquiries have also improved across Asian markets, helping to support acid prices in North east Asia and we expect this trend to continue in the short term.

Acid exports from Japan have been tighter, adding to the firmer tone in the region. Exports in January – February were 3% lower than a year earlier. Volumes to Thailand saw a boost however. Sumitomo announced on 3 April maintenance work is scheduled for its Toyo smelter for 25 days during 2017. Trade from South Korea also dipped in the first two month of the year to close to 400,000 tonnes, around 15% below year ago levels. We expect to see recovery during Q2/Q3 as production and deliveries normalise.

Moroccan acid imports continue to strengthen through 2017, to levels beyond the record numbers seen in 2016. Imports as of mid-April since the start of the year were tallied at 493,000 tonnes, comparing to just 408,000 tonnes in 4M 2016. Strong trade to Morocco is a positive signal for European producers, and continues to aid in balancing the market.

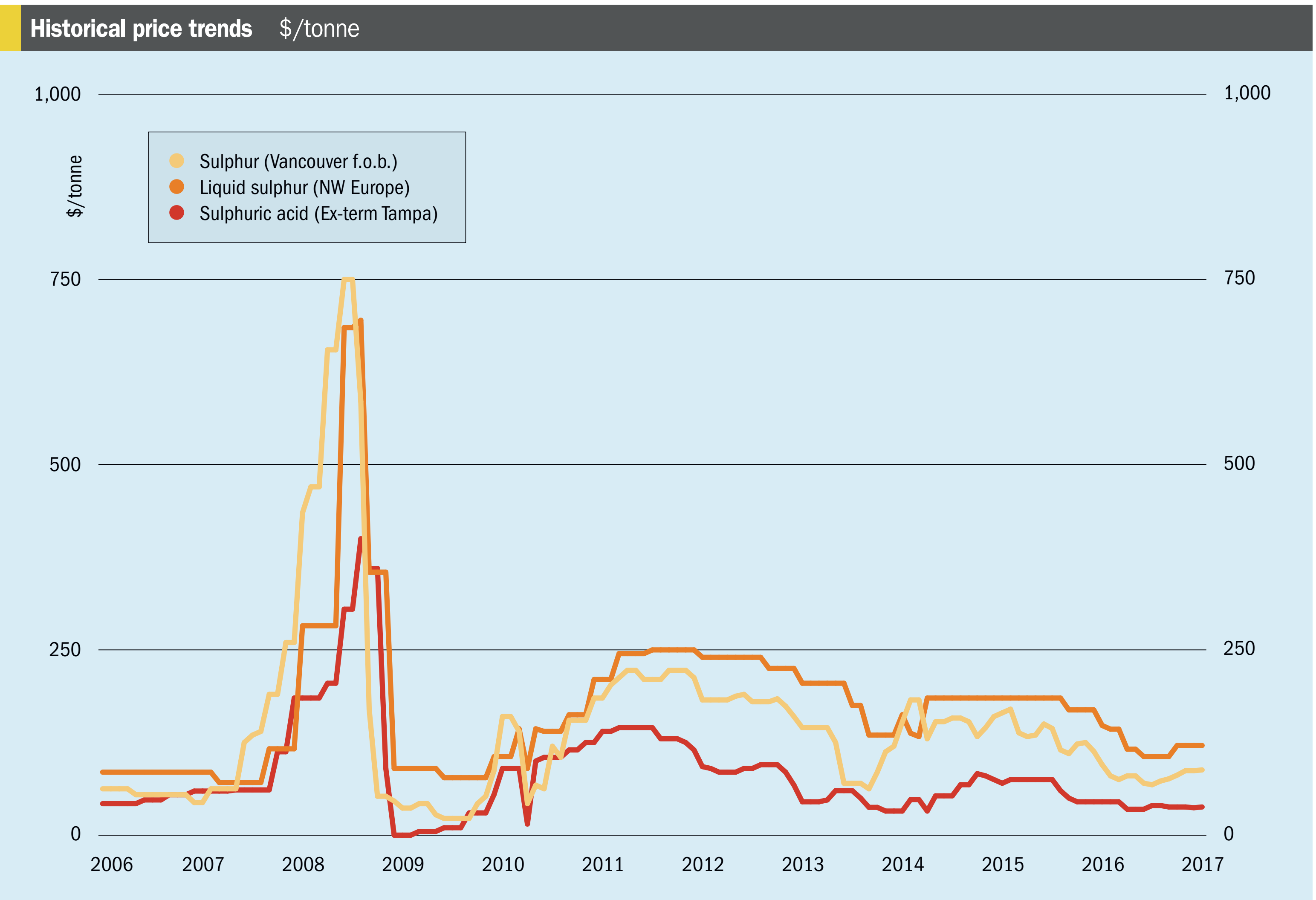
Price indications

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

Cash equivalent	October	November	December	January	February
Sulphur, bulk ($/t)					
Vancouver f.o.b. spot	76	81	87	86	88
Adnoc monthly contract	81	88	92	92	95
China c.fr. spot	97	100	101	98	103
Liquid sulphur ($/t)					
Tampa f.o.b. contract	70	70	70	75	75
NW Europe c.fr.	106	121	121	121	121
Sulphuric acid ($/t)					
US Gulf spot	38	38	38	38	38

Source: Various

Market outlook



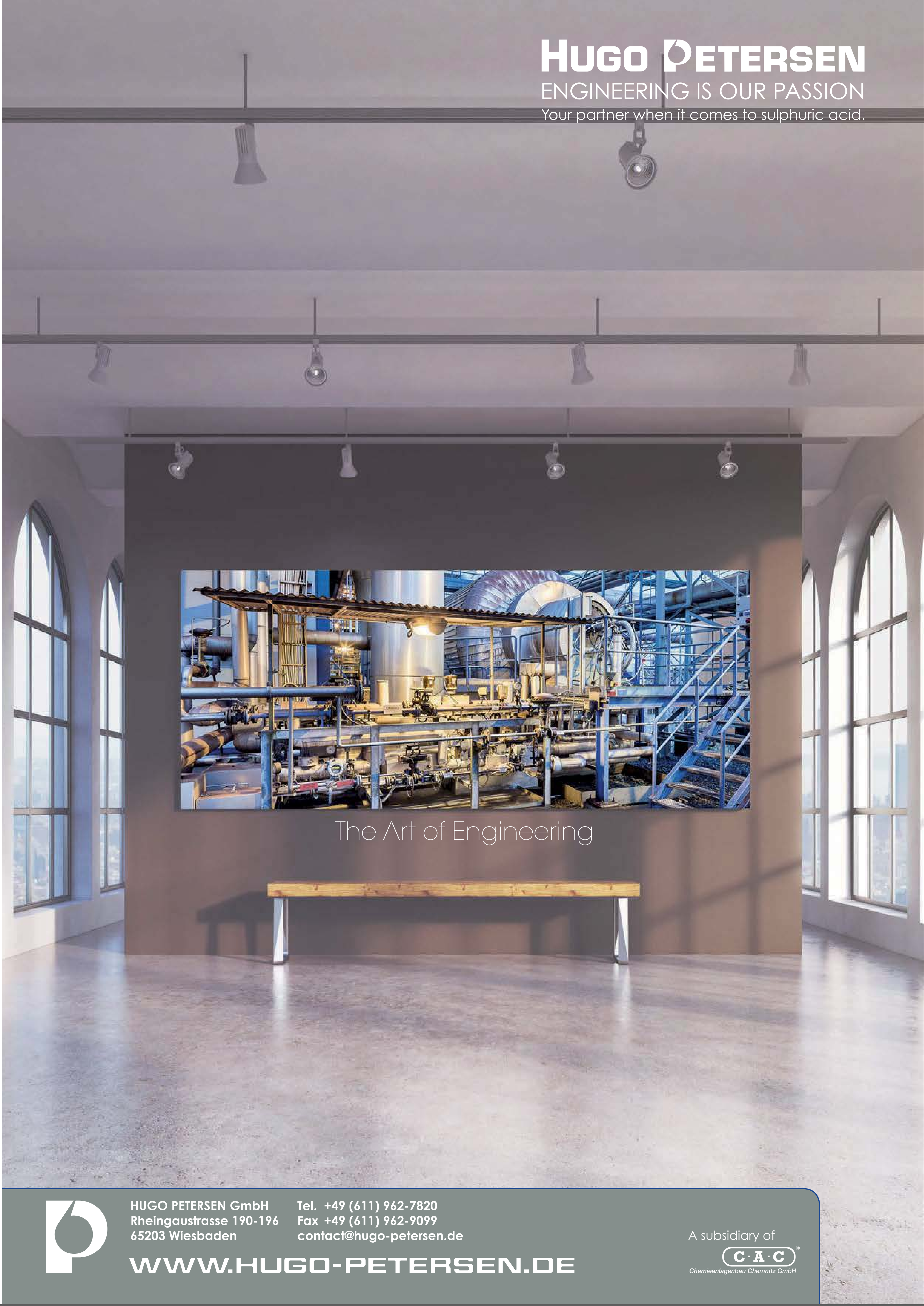
Source: BCInsight

SULPHUR

- On the supply front, the two projects still on the horizon are Kashagan in Kazakhstan and Barzan in Qatar, both are due online this year. We expect to see potential for supply from these projects to impact the market during the second half of the year.
- Activity in China remains crucial for the short and long term outlook. Imports in January – February eroded, and if this continues in the coming months will remain a market bear, putting downward pressure on pricing and trade. Domestic production in China is set to rise this year, potentially impacting the country's sulphur import requirement.
- Demand in regions including Africa and the Middle East will primarily be driven by the processed phosphates sector as new projects expand or come online. Ongoing issues remain however in the downstream markets, with limited recovery and upward momentum in pricing expected – this could lead to a more bearish outlook for sulphur.
- Supply from Russia is expected to see some recovery through Q2 2017 as the winter comes to an end and the waterway is reopened. Exports through much of the first quarter were believed to be largely from stocks, rather than new production.
- **Outlook:** The recent downturn is expected to continue in the short term, due to the softer sentiment and downward pressure from downstream markets. Looking ahead, the second half of the year is set to see an uptick in some areas for fresh supply sources, leading to a bearish outlook for sulphur. However, demand also shows growth through the year, albeit at a slower pace.

SULPHURIC ACID

- Morocco continues to be a major market driver for European acid, with monthly imports a key market development to watch. Surplus acid is being balanced in this market – and is likely to be a bullish supporting factor for the year ahead.
- China acid imports will be a key indicator of demand, with some regional tightness due to turnarounds. The Nanfang Non-ferrous Metals Group entered a turnaround at the end of March for a month at its Guangxi acid plant. The producer increased its prices as a result of the tighter balance.
- Brazilian acid imports totalled 162,000 tonnes in Q1 2017, showing a recovery of 28% year on year – a more positive sign for the market. Trade from Mexico has seen a drop of around 23% – boding well for European trade to Brazil.
- US Gulf spot prices have seen a slight uptick in April. This is expected to continue later in the year due to the heavy maintenance schedule across smelters in North America.
- **Outlook:** The stable to firm trend is expected to continue in the short term – based on the assumption we continue to see Morocco and Brazil in the market absorbing European volumes. However, the softening sulphur market may have some regional impact and the latter part of 2017 is likely to see some downward correction as supply/demand balances normalise in Asia and North America.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Sulphur Industry News

UNITED ARAB EMIRATES

Adnoc aims to double output at Shah

The Abu Dhabi National Oil Company (Adnoc) says that its majority owned Al Hosn Gas joint venture is now operating the Shah sour gas project at 110% of rated capacity, and the company's junior partner, Occidental Petroleum, which holds a 40% stake in Al Hosn Gas, has indicated that it expects output at Shah to double over the next decade. The interim target is for a 50% production increase to 1.5 billion scf/d by 2021, according to Adnoc CEO Omar Al Suwaidi. Foster Wheeler was awarded the front end engineering and design (FEED) contract for this first phase of the expansion in December 2016. The design work is scheduled to be completed by 4Q 2017. Sulphur output at Shah will also increase proportionately, from its present 3 million t/a to 4.5 million t/a in phase one and 6 million t/a in phase two, taking Adnoc's total production to 9 million t/a.

Meanwhile, Etihad Rail says it has now transported a total of 10 million tonnes of solid sulphur since the launch of its first stage operations for Adnoc in September 2014. Sulphur is transported up to 264 km from the Shah and Habshan sour gas processing plants to be exported from the terminal at Ruwais. Two trains per day travel the route, each carrying up to 11,000 tonnes of sulphur, with around 400,000 tonnes delivered per month.

CANADA

Shell cashes out of oil sands business

Royal Dutch Shell has agreed to sell most of its Canadian oil sands assets for a total of $8.5 billion. The move is part of a $30 billion sell-off of Shell assets to clear some of the debts it incurred in the acquisition of BG Group last year. However, it is also said to be a response to investor pressure to respond to concerns about carbon emissions and climate change. Shell says that it is aiming to focus greater effort on cleaner technologies, with $1 billion per year to be invested in renewable energy by 2020, representing 4% of the company's overall annual spend. Up to 10% directors bonus payments are also to be tied to management of greenhouse gas emissions in refining, chemical and upstream operations.

Under the oil sands deal, Shell has agreed to sell its existing and undeveloped Canadian oil sands prospect to Canadian Natural Resources Ltd (CNRL) and to cut its share in the Athabasca Oil Sands Project (AOSP) from 60% to 10%. The company will however continue to operate the Scotford upgrader and the Quest carbon capture and storage project. Shell and CNRL will also buy and jointly own Marathon Oil Canada, which produces 48,000 bbl/d of syncrude from Alberta oil sands.

Shell's Scotford upgrader, Alberta.

Falling oil prices have led to something of a retreat from Canadian oil sands projects in recent years. Shell abandoned its Carmon Creek project in 2015, and earlier this year ExxonMobil took a write-down on the $16 billion Kearl project.

"This announcement is a significant step in re-shaping Shell's portfolio," Shell's chief executive officer Ben Van Beurden said in a statement. "The proceeds will accelerate free cash flow and reduce gearing and make a meaningful contribution to Shell's $30 billion divestment program."

Sour gas producer forced to close down

The Alberta Energy Regulator (AER) has taken the unprecedented step of forcing closure of all wells, pipelines and facilities owned and operated by Lexin Resources Ltd due to health and safety concerns. Lexin, which runs the Marzeppa sour gas processing facility, amongst others, is said to owe over C$1 million in levies for the maintenance and safe monitoring of abandoned 'orphaned' gas wells, as well as C$70 million in security deposits for 'end of life' obligations. AER says that it has "little confidence in Lexin's ability to conduct its operations safely and is taking measures to prevent increasing public safety, environmental, and financial risk" Lexiu have previously had run-ins with AER of non-functioning leak detection systems at sour gas sites, where leaks of H_2S-rich gas pose a potentially severe hazard to life, and personnel lay-offs which could compromise its ability to continue monitoring these sites.

Most of the shut-in wells will be transferred to the Orphan Well Association, an industry-funded group responsible for ensuring the assets are safe until a buyer could be found. The company's assets will be offered for sale by a court-appointed receiver, according to AER.

KAZAKHSTAN

Fluor wins two contracts in Kazakhstan

Fluor Corporation has been awarded a two-year engineering services framework agreement with the North Caspian Operating Company (NCOC) for conceptual studies and front-end engineering for projects in the Caspian region. NCOC operates oil and gas activities under the North Caspian Sea production sharing agreement, including Kashagan, one of the world's largest offshore oil fields, as well as the Kalamkas, Aktoty and Kairan fields in Kazakhstan.

"Fluor is delighted to have been selected by NCOC for these important projects," said Al Collins, president of Fluor's Energy & Chemicals business in Europe, Africa and Middle East. "Through early involvement, we can work with our client to optimize design and construction solutions to deliver capital efficiency. We will leverage our extensive knowledge of executing oil and gas projects in Kazakhstan by applying our unique integrated solutions approach."

Engineering teams from Fluor's offices in Atyrau, Kazakhstan and Farnborough, UK will undertake the studies. Fluor began working in Kazakhstan in 1982. Since then, the company has executed ongoing work in projects ranging from conceptual studies and front-end engineering design to mega undertakings.

Fluor has also been selected by Tengizchevroil LLP (TCO) to execute the front-end engineering and design (FEED) for the Multi-Phase Pump Project in Kazakhstan. Fluor booked its share of the contract value in the fourth quarter of 2016. Part of TCO's major capital program, the project will implement multi-phase pump technology across the gathering network of existing oil and gas facilities at the Tengiz and Korolev fields to maintain crude production by reducing wellhead pressure and increasing well deliverability. The project, which covers FEED, detail design and procurement services, also includes modification or upgrade of some utility systems.

GERMANY

New ammonium sulphate granulation process

thyssenkrupp Industrial Solutions (TKIS) has launched a new process for production of granulated ammonium sulphate. The company claims that the process offers fertilizer manufacturers major greater cost efficiency compared with conventional processes and improved spreading and mixing properties compared with crystalline products.

The new patented process begins with a solution of ammonium sulphate solution, often produced as a by-product of theproduction of caprolactam or in coal burning furnaces. Ammonium sulphate is mixed with an additive in a specific ratio which results in greatly reduced dust formation during granulation and high crushing strength in the end product. In the second step the liquid mixture is sprayed into a fluidised bed granulator and processed into solid granules. The product from the granulator is taken to a screen where oversized pieces are crushed and returned to the granulator, together with under-sized particles. Then the product is conveyed to a storage facility. The granules are round and very hard and therefore resistant to impacts and abrasion.

Through the simultaneous supply of sulphur and nitrogen, ammonium sulphate permits strong crop growth and high yield levels. It guarantees long-lasting nutrient supply and promotes the availability of micronutrients in the soil such as manganese, boron and iron. Ammonium sulphate is currently mostly sold in the form of crystals, which are difficult to incorporate into granulated fertilizer blends. Conventional granulation plants are not able to process ammonium sulphate solutions. Instead they require comparatively high-priced ammonia and sulphuric acid as starting materials.

Following successful lab and bench-scale tests, TKIS built a pilot plant in 2016 with an initial production capacity of 500 kg/h. "Here too all the tests have been successful so we can now scale up the process to industrial scale with capacities between five and 20 metric tons per hour," explains Dr. Mathiak. "Fertilizer manufacturers worldwide will be able to benefit from greater cost efficiency. Granular ammonium sulphate is currently made by very few manufacturers so demand is high and there are great sales opportunities, also in niche markets."

RUSSIA

Contract awarded for Afipsky refinery

CB&I has been awarded a $460 million contract by NefteGazIndustriya, LLC, via project developer China National Chemical Engineering Co., for the Afipsky Oil Refinery Expansion Project in Krasnodar, Russia. The scope of work includes detailed engineering, procurement services, construction management services and commissioning services of multiple process units, including a 2.5 million t/a hydrocracker unit licensed from Chevron Lummus Global, a joint venture between CB&I and Chevron. CB&I previously announced awards for the technology license and FEED contract for multiple process units, as well as detailed engineering, procurement, fabrication and supply of a steam methane reformer for a large-scale hydrogen plant, hydrocracking heaters and Breech-Lock exchangers.

OMAN

SNC to commission sour gas project

Canada's SNC Lavalin has signed a long-term deal for commissioning services across a portfolio of upstream projects operated by Petroleum Development Oman (PDO), via SNC's wholly-owned subsidiary Kentz Overseas Co. Kentz has been awarded a five-year contract to provide commissioning support services, covering full systems completions, commissioning and start-up management, planning, consultancy, supervision, execution and administration of various oil and gas and related facilities. It will support the process of bringing on-stream PDO's Rabab Harweel and Yibal Khuff projects, both of which are scheduled for completion by the end of the decade under engineering and procurement contracts let to the UK's Petrofac.

Rabab-Harweel is a $1 billion enhanced oil recovery scheme, using gas injection in the production of oil and gas from the Harweel cluster and production of gas with condensate from the nearby Rabab reservoir – with completion scheduled for 2019. Yibal-Khuff is an integrated oil and sour gas development, aimed at tapping the sour Khuff and Sudair deposits at Yibal – PDO's largest oilfield – and is scheduled for completion in 2020, also at a cost of around $1 billion.

KUWAIT

Petrofac to design and build sour gas plant for KOC

Petrofac has won a three-year contract worth roughly $1.3 billon from the Kuwait Oil Company to design and build a gas gathering centre in the Burgan oil field, in the southeast of the country. The engineering, procurement and construction (EPC) of the first sour gas gathering centre to be developed in the field is scheduled for completion by the middle of 2020. The GC 32 gathering centre will process crude oil and associated gas recovered from the highly sour Arifjan, Marat, Minagish Oolite and Burgan Wara fields.

Petrofac's chief operating officer, Marwan Chedid, said: "Kuwait is one of our core markets in the Middle East and we have been executing projects in the country since the early 1980's. We are proud to continue our association with KOC and look forward to working closely with them to deliver the project."

INDIA

More sulphur from refinery modernisation

Hindustan Petroleum Corp. Ltd. (HPCL) has let a contract to Honeywell UOP to deliver technology licensing and design for process units to be added as part of HPCL's Visakh refinery modernisation project at the 8.3 million t/a Vishakhapatnam (Visakh) refinery in Andhra Pradesh, on the country's southeastern coast. Honeywell UOP will license and design an isomerisation and a hydrocracking unit to help meet rising demand for Bharat Stage (BS) VI-grade fuels (equivalent to Euro 6-quality fuels) in accordance with the Indian government's proposal to reduce carbon emissions by 35% by 2030. The refinery modernisation process will also expand the refinery's processing capacity by 6.7 million t/a to 15 million t/a, as well as boosting its production Euro 4 and Euro 5-compliant low sulphur fuels, and includes two 360 t/d sulphur recovery units (720 t/d total, including tail gas treatment), two 540 t/h amine regeneration units, and a 112,000 t/a sulphur recovery LPG treating unit. ■

Sulphuric Acid News

PERU

No bidders again for La Oroya smelter

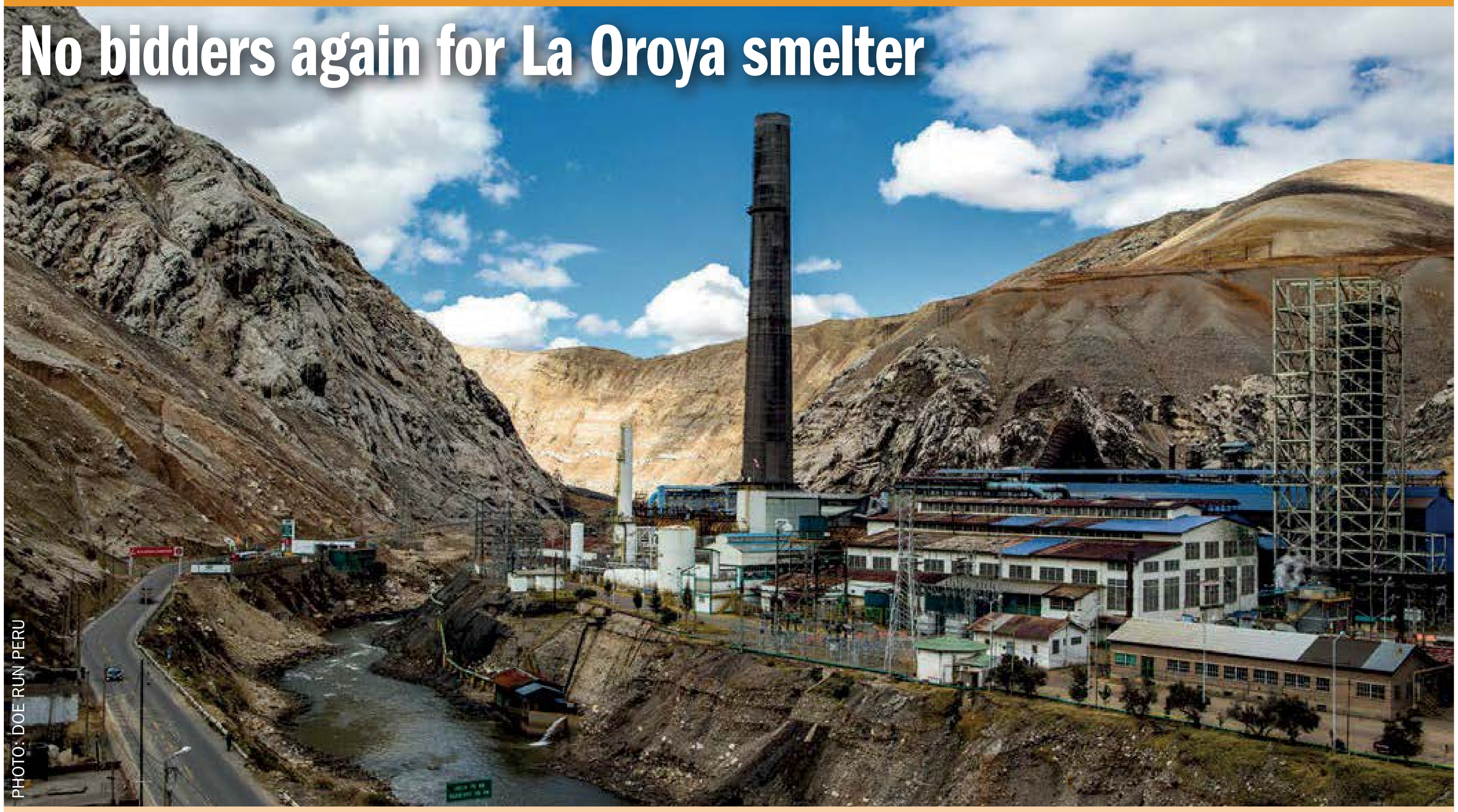


PHOTO: DOE RUN PERU

Peru's third auction of the La Oroya smelter this year on March 30th once again failed to secure a bidder. Potential buyers are reportedly waiting for news on a potential loosening of air quality regulations, particularly as regards sulphur dioxide emissions. Peru's regulations on SO_2 are more stringent than other countries in the region, such as Chile and Mexico, and the Peruvian Environment Ministry has proposed lifting domestic standards to match those of neighbouring countries in order to try and attract interest in purchasing the shuttered La Oroya plant and the associated Cobrizo copper mine.

The smelter was owned and operated by Doe Run Peru, controlled by New York-based Renco Group, but the company went bankrupt in 2009 due to falling metal prices. The zinc and lead circuits were restarted for a while in 2012-14 by Right Business, an administrative consortium of Doe Run's creditors, but the restart of the copper smelter was prohibited, and remains waiting for environmental remediation work, including a 1,000 t/d sulphuric acid plant, to be completed. An attempt to sell the smelter failed in 2015, and the Peruvian government extended the bankruptcy decree to allow the possible intervention by a Chinese consortium, but refused to change environmental emissions standards. However, the new Peruvian government which took office under president Pablo Kuczynski in 2016 has made it a priority to ramp up Peru's refining capacity to add value to the country's copper exports, the second largest in the world, and clearly sees loosening emissions regulations as a price worth paying in order to achieve this. A new auction is now set for August 2017.

CHILE

New acid plants for Chuquicamata

DuPont subsidiary MECS Inc says that it has been selected to supply the sulphuric acid production technology for two new acid plants for the Corporación Nacional del Cobre de Chile (Codelco). The MECS plants will treat off-gas from the Chuquicamata copper smelter complex in the Antofagasta region of northern Chile. MECS partner SNC-Lavalin, will provide the detailed engineering, procurement and construction (EPC) services for the new plants, each of which is expected to produce 2,048 t/d of market-grade sulphuric acid. These plants will replace existing facilities which have become environmentally obsolete.

"MECS technology for Chuquicamata will be designed and custom-built to address the site's specific needs, especially achieving world-class low emissions and high reliability," said Kirk Schall, executive vice president, MECS. "We are delighted that our sulphuric acid production technology will help Codelco's Chuquicamata site realise its short and long-term emissions targets while supporting the sustainable production of the Antofagasta region's most valuable resources. MECS looks forward to partnering with both Codelco and SNC through start-up and with Codelco throughout the life of the new facilities."

Construction of the two new plants will begin in 2017 and is expected to be completed the following year.

UNITED STATES

Lawsuit over phosphate expansion

Four environmental groups are suing the US Army Corps of Engineers, Department of the Interior, and Fish and Wildlife Service in an attempt to prevent the expansion of Mosaic's South Pasture Extension mine near the Peace River watershed and the development of three new mines in central Florida. The groups, including the Centre For Biological Diversity, Manasota-88 Inc., People For Protecting Peace River and Suncoast Waterkeeper have filed a federal lawsuit claiming the agencies violated environmental rules by approving four phosphate mining permits, and argue that the development will destroy more than 57,000 acres of wetlands and woodlands.

New York state seeks to tighten regulations on acid shipments

Thomas DiNapoli, the New York state Comptroller (financial overseer), has written to president Donald Trump and his Federal transportation secretary Elaine Chao to seek additional safety measures for trains carrying hazardous materials in order to protect residents. DiNapoli says that the call is a response to a recent derailment at Newburgh in upstate New York in which a 77-car train carrying sulphuric acid and sodium hydroide, amongst other things, left the tracks. Although there was no leak of cargo, DiNapoli says that additional safeguards are needed to ensure the safe transport of petroleum and other materials by train, and that rail companies should be required to carry insurance sufficient to cover clean-up costs.

CANADA

Strikes halve output at zinc smelter

Noranda Income Fund said that zinc output at its Salaberry-de-Valleyfield plant near Quebec City, the second-largest in North America, was at 50-60% of normal operating levels due to strike action which began on February 12th. The smelter typically produces 275,000 t/a of zinc, and similar volumes of sulphuric acid. Zinc prices have been rising to nine-year highs due to tightness in the market, which the Noranda strike – in its eighth week at time of writing – is exacerbating. The strike affects 371 workers of the 575 at the plant, and concerns proposed changes to pension provisions in a new collective bargaining arrangement. A skeleton staff of non-unionised workers continues to keep the plant operating, but at reduced levels.

Arianne Phosphate appoints project management consultants

Arianne Phosphate has signed of a memorandum of understanding with SNC-Lavalin and Cegertec to jointly act as project management consultants and provide project management support, coordination and consulting for the Lac a Paul phosphate project which Arianne is developing.

"Arianne has put a lot of pieces in place over the last few weeks which provides for the development of many aspects of our project," said Jean-Sébastien David, Arianne's COO. "The involvement of SNC and Cegertec will allow for the integration of all of these pieces into a fully functioning plan that should help us achieve engineering, cost and scheduling certainty. Arianne's recent announcements regarding many aspects of Lac à Paul's development; structural and architectural engineering, steel fabrication, construction of the mill and electricity and automation works have all been put in place, while other aspects should be finalized in the coming weeks. The SNC-Cegertec combination will help us see that every aspect is properly coordinated."

RUSSIA

Uranium leach operations continue to ramp up

ARMZ, the uranium mining subsidiary of Russia's Rosatom, says that it has begun development work at the Vershinnoye uranium deposit in Buryatia, southern Siberia. ARMZ said that the deposit has 4,577 tonnes of uranium reserves and that first production by in situ leaching (ISL) would begin in 2018 via its subsidiary JSC Khiagda. Khiagda is already producing from the Khiagdinskoye deposit, which has reserves of 10,849 tU, and will start work soon on the Istochnoye deposit, which has 2,055 tU. Work will gradually progress to the Dybrynskoye, Istochnoye, Khiagdinskoye, Kolichikanskoye, Koretkondinskoye, Namaruskoye and Tetrakhskoye deposits, which collectively have a combined total of 45,000 tonnes of uranium. Exploration work has indicated that the entire Vitimsky Ore Region has about 350,000 tU, including about 250,000 tU suitable for leaching.

Khiagda mined 540 tonnes of uranium last year and aims to increase this to 1,000 tU per annum by 2019. The company has built a 110,000 t/a capacity sulphur-burning acid plant, commissioned in 2015, to produce acid for the uranium leach operations, and continues to ramp up production there as new deposits are tapped.

CHINA

Replacement of chemical fertilizers

The Chinese Ministry of Agriculture has introduced a pilot project to replace 50% of chemical fertilizer use by organic fertilizers in 100 key cities and districts for fruit, vegetables, and tea planting. The pilot is part of China's ambitious plan to achieve zero growth in the use of fertilizer by 2020. The crops in the pilot study currently account for about 40% of total fertilizer use in China, with a total consumption of 24 million t/a. After 2020, if the project is successful, it will be extended to the whole country, according to minister Han Changfu. However, the plan faces several difficulties; the nutrient content of commercial organic fertilizers is only around 5%, while farm animal manure can contain high levels of antibiotics. The focus needs to be on increasing commercial organic fertilizer production if the goal of replacement is to be reached by 2020.

New phosphate projects

One of China's largest phosphorus mining areas, Weng'an County in Guizhou Province, is to increase mined production of phosphorus. The county has estimated reserves of 3.6 billion tonnes of phosphorus ore, mostly ranked as first or second grade. In addition to the 11.5 million t/a increase in mining capacity, the county seeks to invest about $13.66 million in a 100,000 t/a downstream phosphorus trichloride project to support the production of $POCl_3$, $PSCl_3$, PCl_5, and phosphite and phosphate esters, as well as investing $13.08 million in a 40,000 t/a ammonium polyphosphate flame retardant project to support the growing fire retardant coating market in China.

Sulphur purchasing agreement

The main phosphate compound fertilizer enterprises in China; Yuntianhua Group, Guizhou Kailin, and Wengfu Group, agreed on a strategic cooperation framework agreement for the joint purchase of sulphur in mid-February 2017. The agreement is intended to lead to the establishment of a sulphur purchasing cooperation platform. According to the companies, this is a necessary counterbalance to rising sulphur prices at a time of falling fertilizer prices. In fact the cost of sulphur accounts for about 30% of the total production costs of the compound fertilizer product. The three enterprises are responsible for 33% of China's sulphur demand, of which about 80% is being. The companies are hoping for stronger negotiating power with international suppliers by setting up this purchasing cooperative.

Study on phosphogypsum use

A study began in March on the utilisation of phosphogypsum, jointly organised by the Institute of Process Engineering, the Chinese Academy of Sciences and Hubei Shenglei. The Chinese phosphorus industry is expected to move towards more environmentally friendly and sustainable operation, and the study will research and develop methods for the safe pre-treatment of phosphogypsum, separation and extraction of associated resources of phosphogypsum, and the use of building materials made from phosphogypsum, as well as associated equipment.

Contract for sulphuric acid regeneration unit

Zhejiang Petroleum and Chemical Co. (ZPC) in China has awarded contracts for the engineering, technology license and proprietary equipment for a MECS sulphuric acid regeneration (SAR) unit, licensed by DuPont Clean Technologies. ZPC is constructing a greenfield refinery and petrochemical project on Dayushan Island, just off the coast of eastern China, near Shanghai and Ningbo. The $15 billion project, the largest privately-led petrochemical and refining project in China, will be executed in two phases, the first due for completion in late 2018. After completion, the complex will have a refining capacity of 800,000 barrels per day.

The regeneration unit will have the capacity to regenerate 858 t/d of spent sulphuric acid, producing a combination of products including of 98.3 wt-% sulphuric acid, 99.2 wt-% sulphuric acid, and 20% oleum. It is designed to meet the Chinese Ministry of Environmental Protection's current emission requirements for SO_2, NOx and sulphuric acid mist. Jason Hartman, global market specialist for the MECS SAR technology said; "China's Ministry of Environmental Protection has enacted some of the most stringent point source emission requirements in the world. DuPont Clean Technologies is uniquely positioned to meet these new standards through enhancements to our MECS SAR technology, including the *Vectorwall*™ furnace, *DynaWave*® scrubbing and *Brink*® mist eliminators."

GERMANY

Sojitz buys Solvadis Holding

Japan's Sojitz Corporation has agreed to acquire 100% of shares of European chemical marketing and distribution company Solvadis Holding Srl. ("Solvadis"), subject to regulatory approvals. Sojitz says that it aims to bolster its chemical business and earnings by making Solvadis a fully-owned subsidiary, acquiring a new business platform in Europe. Sojitz primarily produces and sells methanol in Asia, with sales of more than 1 million t/a, while Solvadis operates sales offices and logistics centres throughout Europe, with a focus on Germany, and has strengths in sales of basic chemicals such as sulphur and sulphuric acid, as well as methanol, of which it handles more than 1 million t/a. Sojitz says that it aims to create synergies within the basic and specialty chemical sectors, integrating the marketing and distribution strengths of Solvadis Group in Europe into Sojitz's global sales network.

PHOTO: TATA CHEMICALS

Tata Chemicals' fertilizer plant in Haldia, West Bengal.

INDIA

Tata forced to close Haldia over environmental violations

India's Central Pollution Control Board (CPCB) has forced Tata Chemicals to temporarily shut down its fertilizer plant in Haldia, West Bengal, for violating liquid waste discharge rules. The company said that it has written to the CPCB to rescind the order after an independent lab confirmed that its samples comply with prescribed norms. The Haldia site has a capacity of 1.2 million tonnes per annum of fertilizer, including DAP, NPK and SSP, and operates two sulphuric acid plants with a combined capacity of 250,000 t/a.

Mitsui buys Chemtrade Aglobis

In a similar transaction, Japan's Mitsui & Co has agreed to purchase Chemtrade's Aglobis subsidiary, its European sulphur and sulphuric acid business, for €34 million ($36 million), again subject to elevant regulatory approvals. Aglobis, via its tank terminals, truck and rail car feet, is a leading distributor in Europe for sulphur and sulfuric acid. Mitsui says that it has been developing its sulphur and sulfuric acid business for many years in the Far East, other parts of Asia, and the Middle East, leveraging its specialty logistics assets and trading networks across the world, and now aims to further contribute to the development of the energy, non-ferrous metal and agriculture/chemical industries in Europe by integrating Aglobis's operations at its Zug, Essen and Rotterdam locations. The deal is expected to close in the second quarter of 2017. This transaction will not affect Chemtrade's North American sulphuric acid and sulphur businesses.

AUSTRALIA

Rare earths project raises more capital

Arafura Resources has raised A$3.1 million from a share issue. This follows on from a A$3.6 million capital raising in February which was well supported by institutional investors. The new funds, together with existing cash reserves, will be used to progress the Nolans rare earth pilot project and final feasibility study. Arafura is developing one of the world's largest deposits of neodymium and praseodymium, used in powerful magnets. The company has also recently engaged Prayon Technologies to provide specialist support for operating a phosphate extraction pilot plant at the site. Arafura is aiming to extract phosphate from the concentrate produced from the beneficiation pilot plant and produce phosphoric acid as a value-enhancing by-product.

SENEGAL

Avenira ships first phosphate from Baobab project

Phosphate developer Avenira says that it has successfully completed the first shipment of phosphate rock from the company's Baobab project in Senegal. The MV Leo Star 1 vessel, loaded with 21,400 tonnes of phosphate rock, left Dakar on March 7th, bound for what is described as "an established fertiliser manufacturing site" in India. The shipment is part of Avenira's introduction of phosphate rock to the Indian market and the assessment of its suitability for phosphoric acid manufacturing by the customer.

Avenira said there is approximately 5,000 tonnes of phosphate currently stockpiled at the Port of Dakar, and more

is being delivered by road from the mine site. A second, smaller shipment, this time destined for the European market, was anticipated in April 2017. Avenira said that it had begun transporting its first phosphate rock from the Baobab project site to the port of Dakar, 145 km from the mine, back in October 2016, using 50 tonne covered trucks. Production of phosphate rock began in August, five months after mining began in March 2016. Avenira aims to reach a capacity of 500,000 t/a of phosphate rock production in the first phase of operations at Baobab, with further expansion in later stages. The successful $15 million development of Stage 1, which was delivered on time and on budget, paves the way for Avenira to continue to pursue its strategy of multiple stages of expansion across the Baobab project.

The first successful shipment from Dakar also triggers the conversion of 40 million class B contingent share rights held by Baobab Partners into 40 million fully paid ordinary shares in Avenira, in accordance with the terms of the merger implementation agreement for the acquisition of the Baobab project.

SOUTH AFRICA

Nickel project looks to acid leaching

URU Metals says that it has begun metallurgical test work on nickel ores from its proposed Zebediela Nickel Project to confirm the potential for processing via acid leaching. The company says that the move from froth flotation to acid leaching could generate a "significant" capital expenditure saving, improving the returns from the project and potentially improving the recoveries of nickel in excess of 54%, further bolstering the project's economics. Zebediela, located in Limpopo Province, has a combined inferred and indicated mineral resource estimate of 1.5 billion tonnes of nickel.

PHILIPPINES

Japan firms looking at nickel expansions

Japanese business are looking at investments totalling $4 billion in the Philippines, according to the country's Department of Trade and Industry (DTI). Philippines Trade and Industry Secretary Ramon M. Lopez met with senior executives of Japan's seven major trading houses in Tokyo on March 1st to discuss president Duterte's economic programs and Japanese companies investment interests in the Philippines. As well as coal-fired power plants and Mindanao farming expansion projects, the Japanese firms are looking at additional nickel mining in Surigao and Palawan, and Sumitomo, Sojitz and Mitsui are said to be considering investments of $1.6 billion in expansions at the Coral Bay Nickel Corp. and Taganito High Pressure Acid Leaching Nickel Corp. in Surigao and Palawan. Sumitomo Metal Mining (SMM) recently bought out Nickel Asia's share of the Taganito operation for $42 million.

JAPAN

Mitsubishi takes additional smelter output

Japan's Mitsubishi Materials Corp says it plans to produce 177,000 tonnes of refined copper from April-September 2017, a 13% increase on the same period for 2016. Mitsubishi is Japan's third largest copper smelter, and says that it expects output at its Naoshima Smelter and Refinery in western Japan to rise 4%, while production at Onahama Smelting and Refining, north of Tokyo, jointly owned with Dowa Holdings and Furukawa, to rise by 30%. As part of an agreement between the partners, Mitsubishi is gradually taking a part of the smelting capacity previously assigned to Dowa.

INDONESIA

Indonesia export ban lifted

At the same time as Tanzania is imposing an ore export ban, Indonesia seems to be rowing back on its own comparable move. The country's Energy and Mineral Resources Ministry has granted Freeport-McMoRan a temporary permit to resume exports of copper concentrate from Freeport's massive Grasberg Mine in Papua Province. Freeport will be allowed to ship up to 1.1 million tonnes of copper concentrate – its previous annual quota – at least until October. However, the government says that a permanent exemption will be subject to the issuance of a new permit which required the company to comply with changes in tax policies and to eventually divest majority stakes in mines to Indonesian parties. Freeport has been resisting the new permit terms, demanding that the government provide "legal and fiscal guarantees" that would enable it to operate beyond 2021, when its current contract expires. It has so far divested 9% of shares in Grasberg, but the government is pressing for this to be an eventual 51%.

Indonesia has also relaxed export rules on nickel ore and bauxite provided that companies can show progress towards development of domestic smelting and processing capacity. The move caused a 5% fall in the price of nickel, which had been riding at nine-year highs following the cut in exports from Indonesia, previously one of the largest suppliers, and has angered Chinese companies which have already invested in processing capacity in Indonesia. There is believed to be up to 20 million tonnes of nickel ore stockpiled in Indonesia which may now be free to move abroad.

Vale to proceed with HPAL nickel plant in Sulawesi

PT Vale Indonesia, the local subsidiary of Brazil's giant mining company Vale, says that it is going to build a $2 billion ferronickel smelter in Pomalaa, in the southeast of the island of Sulawesi. The construction of the new facility is due to begin in 2018, with operations to begin in 2023. At present, Vale says that it is waiting for forest area utilisation permits and is in the process of revising the environmental impact analysis for the project.

Vale is partnering Japan's Sumitomo Metal Mining Co. Ltd. to develop high pressure acid leaching (HPAL) technology for the Pomalaa processing plant, and says that it is looking for another partner to help produce the ferronickel in the facility.

TANZANIA

Government bans export of ore concentrates

The Tanzanian government's Ministry of Energy and Minerals has banned all exports of gold and copper concentrates from the country, effective from March 2nd. The motive appears to be to help develop a domestic smelting industry, in much the same way as Indonesia has tried to do, rather than ship ores and concentrates overseas for processing. However, in the interim, local miners such as Acacia face considerable disruption. At the moment mines are still operating and gold and copper concentrate is being stockpiled, but Acacia has said that; "during April we will reassess how long we can continue to produce as normal if the ban remains in place and what other measures may be necessary." ■

1 47 2 48 3 49 4 50 5 51 6 52 7 53 8 54 9 55 10 56 11 57 12 58 13 59 14 60 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

People

Rory Ferguson

Specialist oil and gas recruitment company Petroplan Group has announced the appointment of **Rory Ferguson** is its new chief executive officer. He joins Petroplan from recruitment firm Lawrence Harvey, where he spent three years as group managing director, overseeing a period of rapid growth and developing a new leadership team. Prior to this he spent four years at international recruiter Hydrogen, starting up the company's oil and gas team and expanding it to become an international practice representing 20% of the Group's gross profit. Fergusom has a BA in History from the University of Southampton, and also served as an officer in the British Army for four years.

John Reeder, Co-Founder and Chairman of Petroplan, commented: "We are delighted to have Rory on board, given his very impressive track record and over twenty years' experience in recruitment. I and the rest of the Board look forward to working with him as we broaden our scope and deepen the expertise we have under our roof."

Ferguson said: "I've had a passion for the oil and gas sector for many years, but the opportunity to assume the leadership role within a well-known and respected international player like Petroplan was too good to pass up. Over the coming weeks, I'll be working with the Board to build a strategy which I'm confident will include an element of diversification. But we won't be straying too far from our primary market, where I believe value remains in the longer term. In terms of Petroplan's own people, I think we've got some great talent in the business. Where possible we'll always try to grow organically and promote from within, but we will acquire experience if we feel it can give us a strategic edge."

Cairn India, the country's largest private oil and gas exploration and production company, has appointed senior oil & gas advisors, **Melody Meyer** and **Atul Gupta**, to "provide strategic direction and delivery focus" to Cairn India, as the company expands to represent 50% of India's overall crude production, sustaining production at 300,000 barrels of oil and oil equivalent per day.

Meyer has 37 years of experience with Chevron Corporation, one of the world's largest integrated oil companies. In her last role as president, Asia-Pacific, she was responsible for driving Chevron's E&P activities across nine countries in the region. She has extensive leadership expertise in global upstream operations, strategic business planning, major capital projects execution and capital allocation. In her earlier roles at Chevron, she has served as President of Energy Technology, Vice President of the Gulf of Mexico strategic business unit, and Vice-President US Mid-Continent and Alaska unit. An American citizen, she graduated from Trinity University in 1979 with a BS degree in Mechanical Engineering and attended Dartmouth Tuck Executive Education program in 1997.

Atul Gupta currently advises private equity firms and sits on the boards of a number of upstream oil and gas companies including Nostrum (Kazakhstan), Seven Energy (Nigeria) and Vetra Energy (Colombia). In a 37-year career in the industry he was previously chairman and CEO of BSG Resources – a natural resource and power company – and CEO of Burren Energy Plc. He has also worked with Charterhouse Petroleum, Petrofina, Monument and was also the managing director of Hindustan Oil Exploration Co. Ltd., of HOEC Bardahl India Ltd. from 2006 to 2008. A British citizen, he holds a Bachelor's degree in Chemical Engineering from Cambridge University and a Master's degree in Petroleum Engineering from the Heriot-Wat University.

Speaking on these appointments, Sudhir Mathur, acting CEO, Cairn India said: "It gives us immense pride to have Ms. Melody Meyer and Mr. Atul Gupta with us. With their unique blend of extensive oil and gas experience, leadership and business acumen, we are confident that they will together play a stellar role in further increasing the operational efficiency and growth of our business. They will prove to be the twin pillars on which Cairn India's forward vision will be founded." ■

Calendar 2017

APRIL

27-28

Sulphur Solidification and Handling Seminar 2017, ATHENS, Greece
Contact: Sandvik Process Systems,
Email: elke.schneider@sandvik.com
Web: www.sandvik-sps.de/sulphur2017

MAY

8-10

SYMPHOS 2017,
MARRAKECH, Morocco
Contact: OCP
Email: info@symphos.com
Web: www.symphos.com

9-12

SAIMM Sulphur and Sulphuric Acid Conference 2017,
CAPE TOWN, South Africa
Contact: Camielah Jardine,
South African Institute of Mining and Metallurgy, P.O. Box 61127,
Marshalltown 2107, South Africa
Tel: +27 (11) 834-1273/7
Email: camielah@saimm.co.za

JUNE

7-8

ESA General Assembly 2017, ATHENS, Greece
Contact: European Sulphuric Acid Association,
Avenue E. van Nieuwenhuyse,
4/2B-1160 Brussels, Belgium
Tel: +32 (0)2 676 7253
Email: pdh@cefic.be
Web: www.sulphuric-acid.org

9-10

41st AIChE Annual Clearwater Conference 2017,
CLEARWATER, Florida, USA
Email: chair@aiche-cf.org
Web: www.aiche-cf.org

OCTOBER

2-6

Phosphate Fertilizer Production Technology,
MARRAKECH, Morocco
Contact: International Fertiliser Society,
PO Box 12220, Colchester, CO1 9PR, UK
Tel: +44 1206 851819
Email: secretary@fertiliser-society.org

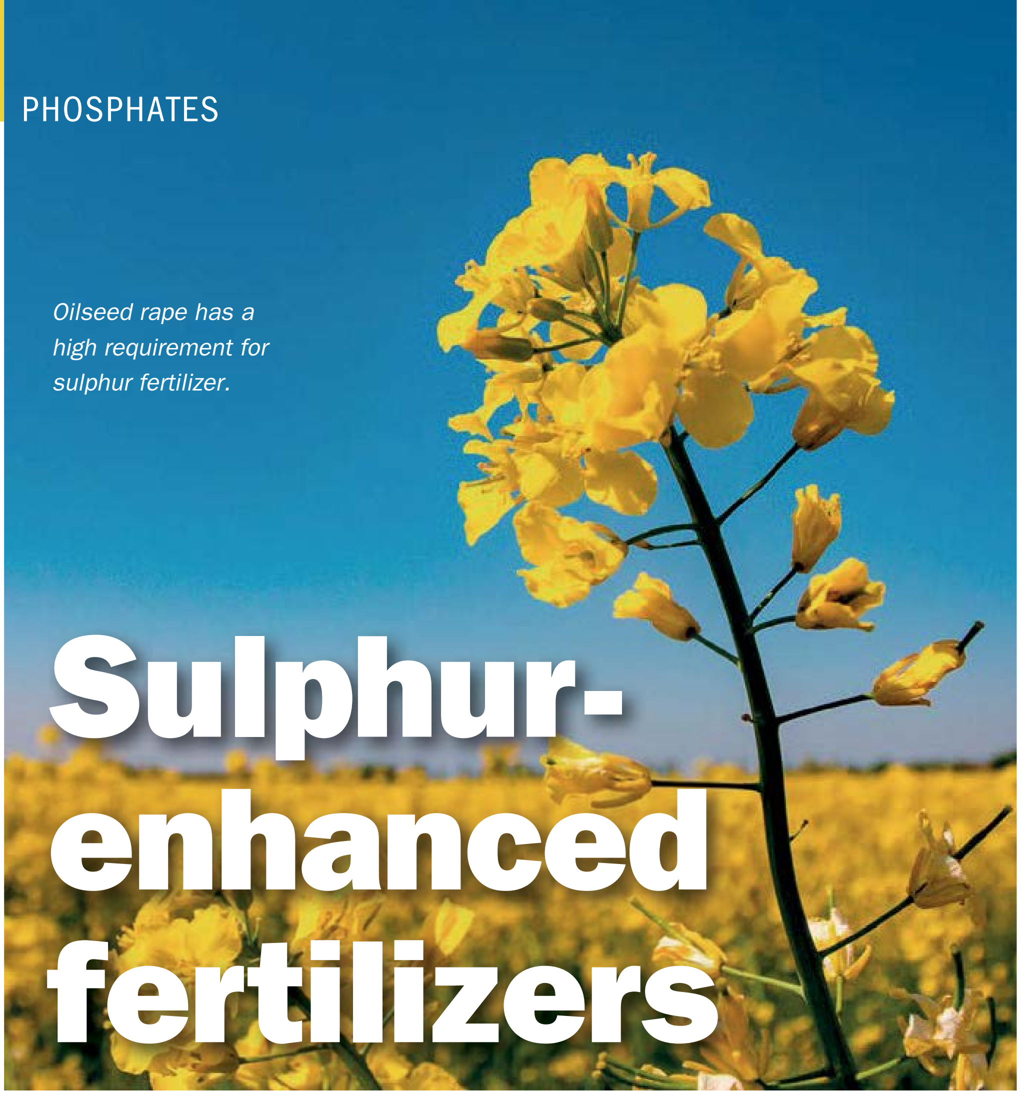
9-11

MESPON 2017
Contact: UniverSUL Consulting, PO Box 109760, Abu Dhabi, UAE
Tel: +971 2 645 0141
Fax: +971 2 645 0142
Email: info@universulphur.com

NOVEMBER

6-9

Sulphur 2017, ATLANTA, Georgia, USA
Contact: CRU Events. Tel: +44 20 7903 2167
Email: conferences@crugroup.com



Oilseed rape has a high requirement for sulphur fertilizer.

PHOTO: PAVEL KLIMENKO/SHUTTERSTOCK.COM

Sulphur-enhanced fertilizers

Companies are now increasingly offering fertilizers with additional sulphur nutrient content as a way of enhancing yields and helping to combat sulphur deficiencies in some parts of the world.

The major source of demand for sulphur and sulphuric acid continues to be from its use in the preparation of fertilizers, particularly phosphate fertilizers. Modern agriculture requires the application of large tonnages of elemental nutrients in order to replace those removed from the soil by plant growth, and key amongst these, after nitrogen, is phosphate. Conversion of phosphate-bearing rocks into phosphate fertilizer is achieved via the application of sulphuric acid, and phosphate fertilizer demand accounts for around 56% of all sulphuric acid use, mainly as the fertilizers single superphosphate (SSP), produced from direct application of sulphuric acid to phosphate rock, triple superphosphate (TSP) – like SSP but with an intermediate step where the sulphuric acid is used to produce phosphoric acid, which is then reacted with phosphate rock – and the higher analysis fertilizers mono- and di-ammonium phosphate (MAP/DAP), which require the reaction of ammonia with phosphoric acid (which in turn has been produced from sulphuric acid).

As important as phosphate is as a fertilizer, however, after the classic 'big three' nutrients (nitrogen, phosphorus and potassium – N, P and K), the next most commonly required nutrient to facilitate plant growth is sulphur, and its absence can be a brake on the uptake of other nutrients, stunting plant growth. Sulphur is involved in the development of protein and chlorophyll in plants, and many enzymes essential for biochemical reactions within the plant cell are activated by sulphur. As a nutrient sulphur improves the percentage of oil in oilseed crops, especially important for production of vegetable oils, and increases the protein content of seeds. It improves the baking and milling quality of cereals and increases the nutrient value of forages. It is also responsible for the odour and flavours of some vegetables in the cabbage family, and improves plant resistance to cold and disease.

Furthermore, sulphur deficiency in soils is an increasingly recognised phenomenon worldwide. The reason that it is a relatively more recent phenomenon, and had never been much of a problem prior to the 1970s or 1980s, can be explained by what had been up to that point the 'silent' application of 'invisible' or 'free' sulphur to fields, from two main sources. The first was the types of fertilizers in common use at the time – including ammonium sulphate, single superphosphate (SSP), and potassium sulphate, which all had a sulphur component, even though they were being applied primarily for their N, P and K content respectively. The switch away from these to higher nutrient NPK content fertilizers such as urea and MAP/DAP greatly reduced this source of sulphur being applied to soils. The second development was the recognition of the damage caused by sulphur dioxide to both human health and the environment, in the latter case especially because of the so-called 'acid rain' phenomenon whereby airborne SO_2 reacts with water to form sulphonic and sulphuric acid, which is then carried back to the ground. This led to a wholesale move to reduce SO_2 emissions from all combustion processes, in cars via the mandating of ever-lower sulphur fuels, and in power generation via scrubbing of stack gas emissions to atmosphere to remove SO_2. The amount of sulphate being carried to the ground has fallen rapidly because of these practises, and while this has had an undoubted benefit for human health, it has removed sulphur which was being used by plants. It is reckoned that Europe suffered an average decline in sulphur applications to soils from 50 kg/ha to 10 kg/ha from the 1970s to the 1990s.

The consequence is that a market has gradually begun to emerge for sulphur-containing fertilizers in their own right, and such are the levels of sulphur deficiency in soils in areas such as China and India, that the Sulphur Institute (TSI) estimates that the potential deficit for sulphur around the world was as much as 12.5 million tonnes of sulphur per year in 2015. China and India collectively represent about 40% of this deficit, with Africa and North and South America another 33% between them, as shown in Table 1. This means that there is a potential market for another

Table 1: Estimated sulphur deficit by region, 2015

Region	Sulphur deficit, million t/a
Asia	6.7
of which China	2.6
India	2.1
Africa	1.6
North America	1.5
South America	1.0
Europe	1.2
Total	**12.5**

12.5 million t/a of sulphur as a fertilizer over and above what is already consumed, and while other alternative uses for sulphur have been proposed, such as incorporation into structural materials such as concrete and bitumen, or in new varieties of sulphur, but sulphur as a fertilizer definitely offers the best prospect for new large-scale demand.

Sulphur vs sulphate

Sulphur can be incorporated into a fertilizer in two main ways – as elemental sulphur, or as sulphate. The difference is in the availability to the plant; sulphur is only available as a nutrient to plants in the form of sulphate, and cannot be take up as pure sulphur. This leads to a dramatic difference in speed of uptake – whereas sulphate can be removed from the soil in a matter of weeks by plants, it can take up to a year for half of the elemental sulphur present in a standard sulphur granule to be oxidised to sulphate in the soil and be taken up by the plant. While this means that it can be used as a long term or controlled release fertilizer, it does mean that the sulphur may not be available in sufficient quantity during the growing phase unless sown some time before planting. On the other hand, incorporating sulphate into a fertilizer instead of sulphur means that because of the oxygen content there is only one third as much actual sulphur present, weight for weight, which can make sulphate-based fertilizers relatively less efficient in terms of nutrient content and transport.

One potential way around this dichotomy is to include sulphur in the fertilizer but increase the surface area of the sulphur by dividing it more finely, speeding the rate of conversion to sulphate. Research has shown that in order to be oxidised within the growing season, elemental sulphur needs to be present in small particles – less than 150-200 micrometres. Among the solutions is to mix elemental sulphur with bentonite clay – so-called sulphur bentonite. The dry clay absorbs water after the fertilizer is applied, and swells, breaking up the granule and reducing the sulphur into smaller, more easily oxidised particles which can become sulphate over a smaller timescale. Shell, meanwhile, has opted for a different route, by producing very tiny particles of elemental sulphur, 40 micrometres (microns) or smaller, and then dispersing them in existing varieties of fertilizer in a melt or solution. There is more on this technology below.

Table 2: **Sulphur containing fertilizers**

	N	P	K	S
Traditional:				
Single superphosphate	0	16%	0	12%
Ammonium sulphate	21%	0	0	24%
Potassium sulphate	0	0	50%	18%
Gypsum	0	0	0	16-18%
Emerging:				
Sulphur bentonite	0	0	0	90%
Ammonium phosphate sulphate	20%	20%	0	15%
Potassium magnesium sulphate	0	0	27%	22%
Ammonium nitrate sulphate	26%	0	0	14%
Sulphate-NPK compounds	15%	16%	15%	11%

Source: TSI

Other methods of incorporating sulphur involve bulk blending with sulphur-containing compounds, either sulphates or elemental sulphur, but generally calcium sulphate (gypsum). Some trials in Australia and New Zealand have also incorporated elemental sulphur with phosphates with sulphur-oxidising bacteria to speed the rate of decomposition to sulphate, or by partially acidulating phosphate rock (producing in effect a partial SSP). Liquid fertilizers are also produced which contain a mixture of urea and ammonium sulphate solution.

Sulphur fertilizers

Table 2 shows the main types of sulphur fertilizers available, along with their content of the major nutrients. The ‘free’ sulphur from the traditional fertilizers, especially SSP and ammonium sulphate can be clearly seen. However, more recently a range of sulphur-enhanced fertilizer products has become available, whereby sulphur is added to N, NP or NPK fertilizer products via various technologies to provide 5-20% nutrient S. New sulphur enriched fertilizers include elemental sulphur-enhanced DAP and elemental sulphur-enriched SSP, where ordinary superphosphate is enriched with sulphur to make mixtures containing 18 to 35% S. According to The Sulphur Institute, sulphur-enriched SSP, which has become popular in Australia and New Zealand, has superior residual effects to gypsum (calcium sulphate) in areas with high leaching losses of plant nutrients because of its potential for reducing sulphate leaching loss and also providing available sulphate to meet crop needs during the whole growing season. A recent development has been a MAP grade with a 50-50 mix of both sulphate and elemental sulphur, providings readily available sulphur both for early plant uptake and for later in the growing season. These sulphur-enhanced nitrophosphates can also be bulk blended with other fertilizers to produce NPKS variants.

According to TSI, in China, around 3 million t/a of sulphur is applied as SSP, although its production has mainly been as a legacy from an era when production techniques were less sophisticated, and its use has gradually been declining as greater use is made of domestically produced MAP and DAP. However, the Chinese fertilizer market is gradually become more sophisticated, and new sulphur-containing products are coming to the market, including sulphur bentonite and sulphur coated urea. There is also greater use of ammonium sulphate, which is generated as a by-products of China’s burgeoning caprolactam industry. But increasingly there is also much greater use of sulphur enhanced products such as sulphur NPKs – around 10 million t/a of these are now applied every year. India still applies sulphur mainly as SSP – around 6 million t/a of SSP or 720,000 tS/a, but use of SSP is increasing due to its lower cost than imported MAP/DAP, and Coromandel Fertilizers has also now begun to sell sulphur bentonite in India.

In Europe, consumption of sulphur as a fertilizer is much lower, at around 0.5 million t/a of sulphur, but production of oilseed rape for biofuels is a useful boost to sulphur fertilizer demand on the continent. Here, France, Germany and Spain represent the largest diversity of companies and products involved, including micronised sulphur products, sulphur bentonite, liquids, sulphate carriers and compounds with sulphur.

North America, meanwhile, is seeing growth in use of thiosulphate fertilizers such as ammonium and potassium thiosulphate and polysulphide.

Thiogro

One of the most interesting developments in recent years has been the inclusion of micronised sulphur into fertilizers as a more rapidly available form of sulphur. Shell's Sulphur Solutions division has been looking at developing new markets for sulphur for many years, and one of the areas selected as most promising has been sulphur-containing fertilizers. In order to incorporate sulphur into fertilizers, Shell has developed its own technology, called, Thiogro. This technology enables fertilizer producers to safely incorporate micron-sized particles of elemental sulphur and other nutrients into some of the most widely used fertilizers, including ammonium phosphate-based fertilizers, TSP and, most recently, urea. Shell Thiogro sulphur-enhanced phosphate fertilizer technologies have been licensed and installed in fertilizer plants in Asia, North America and Australia, and have produced more than one million tonnes of sulphur-enhanced fertilizers to date. More installations are underway in these and other regions.

Licensing deals

Since the development of the Thigro technology, Shell has been working to gain commercial acceptance for the technology. So far, it has successfully concluded licensing deals with both OCP in Mroocco and CF Industries in the United States. The Shell Thiogro technology is being installed at OCP's Jorf Lasfar site in Morocco, enabling the company – the world's largest producer of phosphates – to expand its portfolio by incorporating micron-sized particles of elemental sulphur into its existing ammonium phosphate, NPKs and current sulphur-enhanced products. In the US, CF Industries has implemented Shell's Thiogro process technology at its Plant City, Florida facility, in the first North American licensing of the process. The product is a sulphur-enhanced mono-ammonium phosphate (MAP) with a nutrient content of 11% nitrogen, 40% phosphorus and 12% sulphur, which CF Industries markets in the US through its established channels and in Brazil and other Latin American countries via partner Swiss trader Keytrade AG, in which CF has a 50% stake.

Urea

As well as phosphates, Shell has now also begun to look at incorporating sulphur into urea, the most popular nitrogen fertilizer in the world – over 180 million tonnes per year of urea are used worldwide, with China and India by far the largest consumers. Sulphur has been introduced into urea before, but usually as a coating on the urea granule. Sulphur coated urea is produced by coating hot urea by molten sulphur polyurethane oil or a microcrystalline wax, with a ratio of around 30%-40% nitrogen and around 20% sulphur. The coating is oxidised slowly from sulphur to sulphate, and only when this has broken down is the urea released to the soil. Urea must then convert to nitrate before it can be taken up by the plant. This gives sulphur coated urea a slow/controlled release quality. However, it also makes it a relatively specialised fertilizer with only niche uses in sectors such as golf courses, professional lawn care and turf, green houses, horticulture and nurseries. A number of fertilizer companies now offer sulphur-coated urea, including Agrium, Israel Chemicals, Syngenta, Yara, Haifa Chemicals, JR Simplot and Koch.

The enhanced sulphur urea product (Urea-ES) takes a different approach by dispersing micronised sulphur in the urea melt before granulation. Shell has partnered with Uhde Fertilizer Technologies (UFT), part of thyssenkrupp Industrial Solutions, who hold the license for the old Norsk Hydro fluid bed granulation technology, in order to develop this. The sulphur particles are dispersed in a urea solution as an emulsion. Particles of sulphur as small as 40 micrometres or less are used, and emulsify into a homogenous dispersion before the solution is fed to the granulator, where the granules are formed by accretion instead of layering. The UFT granulation process is sufficiently flexible to allow the production of Urea-ES without any significant changes. Just as in normal urea granulation, the particles grow collectively through the solidification of tiny droplets on the seed material. The result is a very hard granule, which Shell says is superior in quality to granules produced through layering or agglomeration-based processes. The slow accretion process permits the water present in the urea solution to be thoroughly stripped on a continuous basis, resulting in the end product having a low moisture content, while the even dispersion of the sulphur in the urea results in a homogeneous distribution of micron-sized sulphur particles in the Urea-ES granules. The bulk of the crystallisation heat released as the granule solidifies is removed by evaporating the water in the urea solution. This method of heat release reduces the amount of ambient air required for cooling and the evaporation is highly efficient because it takes place directly on the granule surface. Since 2014, successful pilot plant runs have demonstrated that sulphur-enhanced urea can be safely produced at UFT fluid bed granulation plants with a minimum of retrofitting.

A growth area

The increasing recognition of crop sulphur requirements and soil sulphur deficiency around the world has led to the proliferation of new varieties of sulphur-containing/enhanced fertilizers from a wide variety of manufacturers. This can only be good news for the sulphur industry, as it is starting to lead to the uptake of more sulphur-containing fertilizers in the growing markets of Asia, especially China, but also southeast Asia and India. This in turn is likely to lead to higher demand for sulphur or sulphuric acid by fertilizer manufacturers. Concrete figures are hard to come by, but a growth figure of 4% per year, only slightly above overall fertilizer demand growth, would see the present sulphur usage rate of around 12 million tS/a 14.5 million tS/a over the next five years, or an additional 2.5 million tonnes of net sulphur demand over and above that required for phosphate fertilizers. ■

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Middle East Sulphur

The first CRU Middle East Sulphur Conference took place in Abu Dhabi in February 2017.

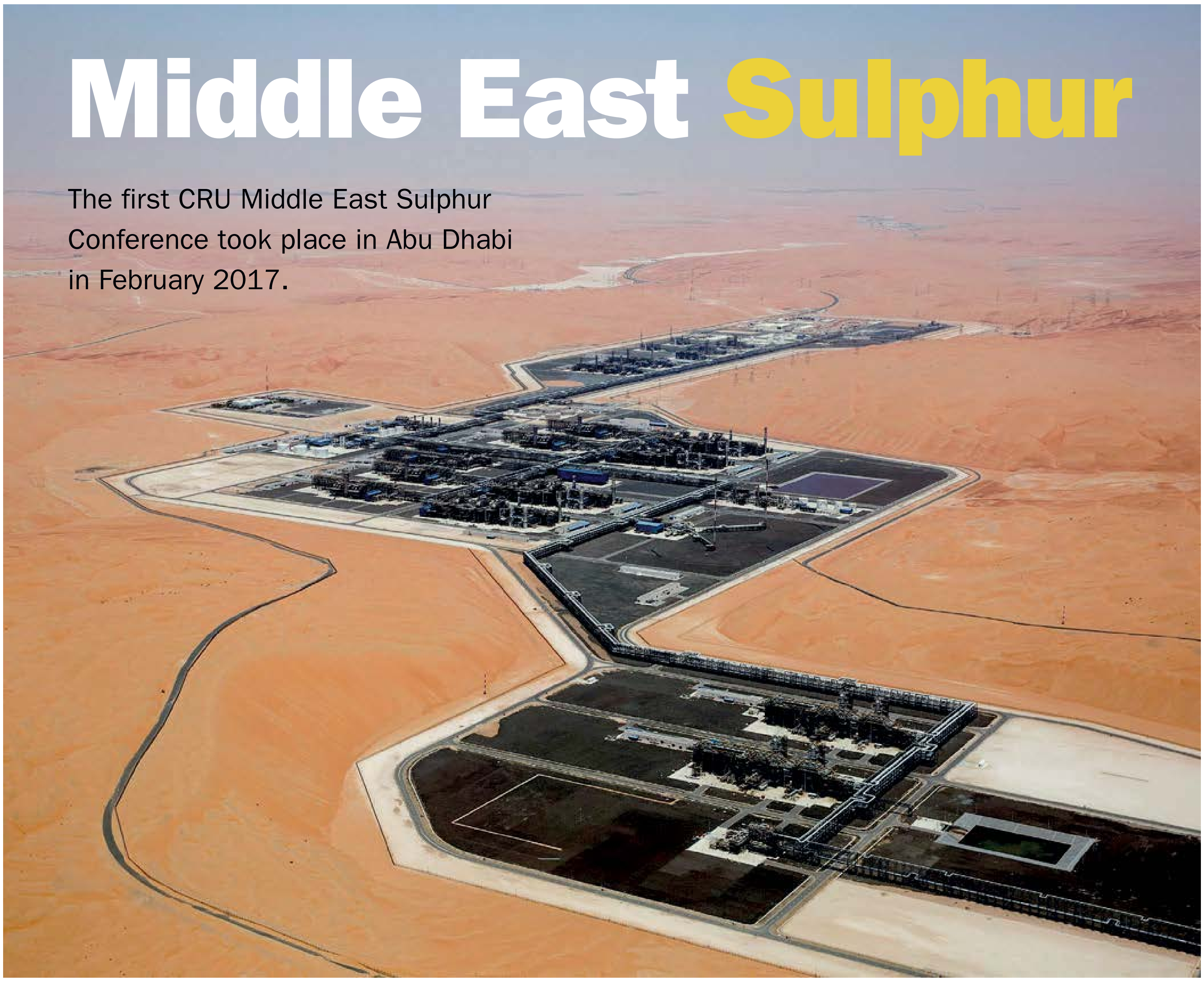


PHOTO: AL HOSN GAS

The Shah sour gas plant, Abu Dhabi.

Perhaps one of the best indicators of the extent to which Abu Dhabi is becoming the new centre of the sulphur world is the rate at which it is attracting sulphur and related conferences. First SOGAT (reviewed elsewhere in this issue), then Brimstone, MESPON and now Middle East Sulphur, with a Gas Processing and Monetisation conference scheduled for May this year.

CRU's foray into the UAE attracted 400 delegates and exhibitors to the Jumeirah Hotel from February 12th-16th, and in his introduction, CRU Group CEO Nick Morgan acknowledged that holding a sulphur conference here recognised that Abu Dhabi in particular has established itself as a centre of excellence in sulphur production and marketing. Giving the welcome address, Omar Suwaina al Suwaidi, Adnoc's gas management director, said that his company is on a journey of strategic transformation into a major sulphur player, and that it aims to maximise the value of the UAE's natural resources. Today Abu Dhabi produces 6 million t/a of sulphur, but over the next decade this figure will almost double, he said cementing its position as the number one exporter of sulphur and turning it into the largest producer of sulphur in the world. Adnoc sees sulphur as a commercially viable commodity in its own right, with a strong future, although he acknowledged that in a low oil price environment it is imperative to effectively manage costs. Adnoc will also support the development of a local sulphur products industry in order to help diversify the UAE economy and provide a domestic market for its sulphur, in such areas as advanced fertilizers, animal feed and via partnerships with international markets for phosphates.

The sulphur value chain

The conference began with an interesting panel discussion led by Angie Slavens, covering the whole sulphur value chain, from production to consumption, following some scene-setting by Hamad Al Raisi, senior market analyst with Adnoc. Adnoc currently produces 6 million t/a of sulphur, said Mr Al Raisi, rising to 6.5 million t/a in the near future, giving it an 11% share of the global market in 2016, up from 4% in 2014. The sulphur is moved from Shah and Habshan to the export port at Ruwais via two trains, each of which can carry 22,000 tonnes of sulphur. Storage capacity is 150,000 tonnes of solid and 55,000 tonnes of liquid at both Habshan and Shah, and 620,000 tonnes of solid and 30,000 tonnes of liquid sulphur at Ruwais. Ruwais has one berth which can handle 11m draft ships and load 1,000 t/h, and two more with a draft of 14.5 metres (up to 80,000 dwt displacement) and 4,000 t/h of shiploading capacity – a 50,000 tonne vessel can be loaded in 36 hours. Mr Al Raisi also noted that the sulphur has a maximum moisture content of 0.5%, and since 2015 has been treated with sodium lauryl sulphate (SLS), allowing export to new markets. Exports have risen from 1.8 million t/a in 2011 to 6.1 million t/a in 2016.

Three price options are offered for sales – a monthly announced price and quarterly and six monthly negotiated contract prices, though the six month contracts are only available for local clients. Registered clients can also access spot cargo pricing. The clients are gradually changing – the balance between traders and end users is about 50-50 by tonnage, although around 80% of actual clients are traders, taking smaller parcels. Adnoc expects sulphur demand growth of around 2-4 million t/a to 2020, or around 3.1% year on year, reaching about 70 million t/a by the end of the decade. Demand growth is mainly in the fertilizer sector, with 40% of this growth coming in Morocco, 11% in China, and 9% each in Southeast Asia and Oceania.

The other panel members included Fahad Al Wahedi process engineering manager for Al Hosn Gas, who covered sulphur recovery; Brian Hait, operations manager of the Shah plant and Hasan Armaneh, operations department head at Habshan V, who discussed sulphur forming and handling; Hamad Al Raisi, covering marketing; Captain Adil Al Maazmi of Adnoc's shipping arm Adnatco, covering shipping; and Youssef Bouslikhane, OCP's director of sulphur and sulphuric acid procurement, speaking as a sulphur consumer.

One of the themes which emerged was that of differentiation via sulphur quality. Maintaining the righgt furnace temperatures minimises BTX contamination. There is analysis of the output of each granulator and each train load is checked against specification, with a further check on arrival at Ruwais. There is careful control of loading, unloading, reclaiming etc sulphur to minimise breakage of the granules and dust formation. At the port, the ships which receive the sulphur must be thoroughly cleaned to minimise acidifcation on long voyages (South America can be 30 days' sailing). Cargo holds must be properly closed and sealed to ensure minimum water ingress, and water is drained via bilges as vibration tends to mean water collects at the bottom of the hold. Customers can to an extent specify moisture content required – 0.5% is standard at production, although in the dry conditions at Ruwais this can fall as low as 0.2%, but there is flexibility to add water if required, balanced against the possibility for corrosion in transit.

As well as product quality, Adnoc also hopes to differentiate itself via customer service, and smooth operations can help the marketing effort. This in turn places a burden of responsibility on the logistics of moving the sulphur, which can be challenging given the huge quantities involved. Shah in particular is further from Ruwais than Habshan and the daily volume of sulphur is higher, so the daily production of sulphur must be loaded onto a train and moved every single day without fail – each train has 3 locomotives and 110 wagons, each carrying 100 tonnes of sulphur. Close coordination with Etihad Rail is required.

The sulphur has other value of course – Mr Al Wahedi noted that the SRUs provide 40% of the power requirement for the Shah installation, and Mr Bouslikhane said that for this same reason, OCP tends to buy sulphur rather than sulphuric acid, to recover heat and power from it when burning it – the company's ability to switch to buying acid when it is cheap amounts to only around 2-3% of its overall acid consumption.

Market outlooks

Peter Harrison of CRU gave the sulphur and sulphuric acid market presentation. Sulphur supply saw a step change in 2015 and 2016, he said, rising 2.8 million t/a and 3.1 million t/a respectively, several hundred thousand tonnes ahead of demand growth, although the supply growth is larger on paper than in physical market terms because of logistically hindered sulphur at remote supply sources, and the opacity of the market has led to an overreaction on the demand side. Trade increased by 1.5 million t/a in each year, displacing local supplies in some places. The main supply increases have been from the UAE and Saudi Arabia, and to a lesser extent the US, and 2017 will see still more sulphur from the UAE on the market, but less from Saudi Arabia as the Umm Wual phosphate site starts up. Demand is increasing in Tunisia and Morocco, and soon Saudi Arabia and India. Phosphoric acid remains the bedrock of the market, said Peter, but industrial demand and metallurgical sulphuric acid is growing faster, albeit from a smaller base. Overall demand should reach 71 million t/a by 2021, he said, in spite of plateauing phosphate output in China. Lower sulphur prices still offer sulphur a chance to displace pyrites as a source of acid in China. Prices have been volatile, bottoming out in the third quarter of 2016 but rising again since then. Markets should be balanced by 2021, he thought, and possibly earlier. Stock builds are likely in places such as Uzbekistan, Iran and Turkmenistan, but he foresaw no large scale blocking of sulphur as yet.

CRU's Philip Macoun expanded on the base metal market and its impact on acid markets. From 2001-16 copper leaching has added an extra 7.2 million t/a of acid demand, nickel leaching 6.2 million t/a, and uranium leaching 2.6 million t/a. On the copper side, demand in Chile peaked in 2012, but there is new leaching capacity being developed in the US and Democratic Republic of Congo (DRC). However, the slump in the copper market led to solvent extraction/electrowinning (SXEW) cutbacks over the 2016-18 period, with up to one third of SXEW plants making a loss. Meanwhile in Zambia sulphur demand for acid for leaching is falling due to displacement by smelter acid from new copper smelters. Overall, there may be another 2 million t/a of acid demand for copper leaching to 2021, mainly in DRC and in the 2018-19 timeframe. Nickel leaching has seem the slow ramp-up of a few very large high pressure acid leach (HPAL) projects, and although the existing projects could still absorb an extra 1.5 million t/a of acid, new nickel capacity is coming from ferronickel, nickel pig iron and nickel sulphide plants, edging out the large volume but more expensive HPAL projects. Looking to the much longer term, Philip saw a peak of acid demand for leaching of 30 million t/a by about 2020, dropping back to 24 million t/a by 2025 due to falling consumption in the copper sector. However, the emerging use of nickel for batteries requires very pure nickel which cannot be provided by ferronickel or nickel pig iron, and that might allow HPAL nickel to command higher prices and perhaps rescue fortunes in that sector in the longer term.

And talking of the very long term, outgoing ASRL research advisor Peter Clark looked to the future of sulphur in a world where energy production is dominated by renewables.

Phosphates

The phosphate market was explored by another panel discussion, this time involving Rajesh Kapur, managing director of Iffco, Youssef Bouslikhane of OCP once more, Robert Wheland of Transcom DMCC, and CRU's Sean Mulholland. Some 34.4 million tonnes of sulphur was consumed in 2016 to make phosphoric acid, representing 56% of sulphur demand, with China, India, Brazil and the US the main demand regions. Morocco and the Middle East drive phosphate supply growth in the medium term, while stagnating demand in China and the US will lead to slipping domestic production. There is considerable growth in large scale integrated phosphate projects, but oversupply has pushed e.g. DAP prices down from \$600/t in 2011 to just over \$300/t c.fr India in 2016. Some discussion ensued about India's self sufficiency programme, and whether this would lead to higher import duties on fertilizers. Mr Kapur said that this remained a possibility, but 100% self-sufficiency is very unlikely and there would always remain room for imports. Affordability remained the most important criterion, however.

Sulphur fertilizers

Another panel discussion looked at the topic of sulphur fertilizers. Peter Harrison of CRU chaired, assisted by Don Messick of The Sulphur Institute and Mike Lumley, general manager of Sulphur & Ventures for Shell. Demand for sulphur fertilizers continues to rise, as awareness of the 'sulphur deficit' in many regions, especially India and sub-Saharan Africa, continues to grow – up to 10 million tonnes S in total – and sulphur is the yield limiting factor for many plants. Demand for ammonium sulphate and potassium sulphate (SoP) are rising, although single superphosphate (SSP) use continues to fall, but the fastest growing area is in NPS multi-nutrient fertilizers, especially in the US, Brazil and Africa. Sulphur fertilizers remain one of the most promising areas for new sulphur demand, and a new sulphur fertilizer market is emerging in China, with more than 10 million t/a of sulphur enhanced NPKs now in use.

Mike Lumley highlighted some of the new technical developments in sulphur-enhanced fertilizers, with micronized particles 40-50 micrometres in diameter dispersed throughout the fertilizer pellet for slower release and greater availability to the plant, and suggested that the sulphur industry needs to coordinate better with the fertilizer industry over this. While the focus so far has been on sulphur-enhanced phosphates, Shell is now close to launching a sulphur enhanced urea product, and is in discussion with a fluid bed granulation manufacturer. Distribution of sulphur fertilizers can be a challenge in India, he said, so incorporating it into urea can be a great opportunity.

Energy efficiency

"Yellow is the new green", said Angie Slavens, discussing energy use in sulphur plants, in a follow-up to the paper she presented at the Sulphur conference in London last November. A sulphur plant is a net energy exporter, but sulphur recovery efficiency and energy consumption tend to act in opposition to each other, especially when using an amine tail gas treatment unit. Beyond 99.9% recovery, towards the 99.98% being talked about in some quarters, you are into net energy deficit, for very little benefit in SO_2 emissions reduction, and carbon dioxide emissions become very much higher – is this really a worthwhile sacrifice for so little incremental SO_2 recovery? One alternative option, she suggested, is to include sulphuric acid manufacture as part of the flowsheet, via something like Topsoe's WSA process. Of course, this depends on there being a local use for the acid, and whether the energy benefits are considered to outweigh the hassle of handling the acid. Nevertheless, a partial acid gas bypass, converting around 50% of the sulphur to H_2SO_4 can generate additional power as well as useful high pressure steam and has an energy balance two or three times better than other cases for 99.9% recovery. For a situation like the UAE, which has 19,000 t/d of sulphur production capacity at present, this could potentially generate 500MW of mechanical power, about half of which would be consumed by the tail gas treatment units for the rest of the sulphur. Peter Clark also suggested that acid neutralisation with ammonia, where available, could generate ammonium sulphate as a useable sulphur fertilizer product.

Jan-Willem Hennipman of Jacobs also focused on tightening SO_2 emissions limits, especially the new so-called 'World Bank Standard' of 99.98%, far more stringent than existing emissions limits, which are 99.5% in Europe and 70-99.8% in Canada, depending on the throughput of the facility. Options to reach 99.98% include; (i) catalytic conversion, via EuroClaus or SuperClaus plus a caustic scrubber; (ii) an amine-based tail gas treatment unit; or (iii) downstream flue gas SO_2 recovery. The capex and opex for these three options run in opposite directions. Up to 99.5% recovery, the catalytic processes are best, but above that things become murkier. At 99.98% recovery the SO_2 recovery option is the cheapest in net present value terms, but has the worst carbon footprint, and so carbon pricing or limits can also have a significant impact on the choice.

Gasco's energy efficiency head Saqib Sajjad discussed the difficulties peculiar to the region, in particular ambient temperatures that can reach 50°C and which fluctuate considerably between day and night. Amine temperature has a major effect on its ability to absorb CO_2 and H_2S, and gas sweetening units use more than 10% of Gasco's total energy consumption, so the concept is to try and use advanced process control to optimise amine temperature by varying solvent flow rate in accordance with ambient temperature in order to save energy. Issues with low temperature foaming are handled by maintaining a 5°C temperature differential between the lean amine and the feed gas rather than a blanket temperature increase. Around a 10% reduction in steam consumption has been achieved in tests.

Sulphur forming and handling

Dust is one of the most important considerations when forming, storing and moving sulphur. Jeff Cooke of IPAC Chemicals discussed the formation of what he called 'dynamic substrate dust', in conveyor transfer, stockpiling, trick and ship loading and unloading and bulk movement via mechanical shovel. The aim is to prevent formation of fugitive dust by preventing the escape of dust particles and generating fewer new ones by adding some lubricity to the sulphur. Adding water on its own does not solve the problem due to sulphur's hydrophobic nature, so a mixture containing sodium lauryl sulphate and other surfactants is added in precise doses – a continuous measurement system using a laser to measure dust formation feeds back into the nozzle dosing system.

Another major issue in sulphur storage is corrosion in liquid sulphur storage tanks, primarily via the deposition of solid sulphur coupled with liquid water from condensation. External heating can prevent this provided that the wall temperature does not go above 160C, and Jose Gil of Controls Southeast showed via CFD modelling that external heating alone can be sufficient to cure the problem, subject to a maximum diameter determined by the heat input rate. Tests using the ControTrace heating system showed good agreement between the model and real world results.

Casey Metheral of Sandvik Process Systems extolled the benefits of Sandvik's RS-1500 single pass externally seeded drum granulator system, latterly purchased from Brimrock, with higher on-stream time and throughput and lower footprint and energy requirements than previous iterations of granulation systems.

Sulphur pipelines

Wednesday morning began with another round table session, this time on sulphur pipelines, with panellists including Mike Allenspach and Anil Lotikar from Pentair Thermal Management, Kent Kalar of Topside Solutions, Scott Wetzel from Al Hosn Gas, Hasan Armaneh from Gasco and Fati Elgendy from Permapipe. The issue of course is that liquid sulphur presents a small operating window between freezing at 120°C and becoming viscous above 150°C. A particular challenge is remelting a frozen sulphur pipeline – because liquid sulphur has a higher volume than frozen, voids form during the freezing process, and collect at higher points in the pipe, which makes even re-heating of the sulphur extremely difficult. Pipe supports and anchors also have different thermal characteristics than pipe sections and can also be focuses for mechanical stress. The measured temperature profile of a pipe can differ from the ideal because of these and be subject to hot and cold spots, and fibreoptics can deliver a continuous measured temperature profile along the pipe, while electrical skin effect heating is much easier to control than steam jacketing. The best solution, of course, is to not let the pipe freeze in the first place, and Scott Wetzel said that extra attention and costs during the design and build phase of the line can pay great dividends in making it more reliable and saving money in the long term. Hasan Armaneh discussed Gasco's planning for a remelt at Habshan, where there are two 8" and two 12" pipelines connecting the processing plants and transferring up to 11,000 t/d, with 70m of elevation difference between the highest and lowest points. Thankfully, he noted, the remelt scheme remains purely theoretical for now!

Propylene manufacture

Alberta Sulphur Research's (ASRL's) contribution to the conference was a paper delivered by Rohen Prinsloo on alkane dehydrogenation using S_2 instead of O_2 as an oxidant. The shift away from naphtha cracking to ethane is leading to a shortfall in propylene production and interest in alternate methods. The advantage of using sulphur to dehydrogenate alkanes is that the C-S bond is more stable than C-O in the reaction temperature range, there is no CO_2 formation, and while some H_2S is formed it can be recycled back to S8 in a Claus reactor. S_2 itself can be generated by high temperature breakdown of S8. ■

Sulphur forming project listing 2017

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

PHOTO: SANDVIK PROCESS SYSTEMS

System manufacturer/ supplier	Operating company	Operating site	Units	Product type	Scheduled throughput	New project/ expansion	Scheduled
BELARUS							
Sandvik Process Systems	JSC Naftan	Naftan Refinery	2	pastille	115 t/d	expansion	2016
CANADA							
Matrix PDM	Heartland Sulphur	Scotford	n.a.	prill	2,000 t/d	new	2017
ECUADOR							
Sandvik Process Systems	Petroecuador	Esmerleldas	1	pastille	100 t/d	new	2016
INDIA							
Enersul	Reliance Industries	Gujarat	8	granule	2,800 t/d	expansion	2017
Sandvik Process Systems	Bharat Petroleum	Ambalmugal	3	pastille	800 t/d	expansion	2017
INDONESIA							
Enersul	Samsung (EPC)	n.a.	1	prill	100 t/d	new	2016
IRAQ							
Sandvik Process Systems	Karbala Refinery	Karbala	4	pastille	360 t/d	new	On hold
Enersul	GazpromNeft	Badra	1	granule	350 t/d	new	2017
IRAN							
Zafaran	NGC	South Pars 20/21	4	granule	1,440 t/d	new	2017
Zafaran	Petropars	South Pars 19	2	granule	1,440 t/d	new	2017
Zafaran	NGC	South Pars 17/18	8	pastille	800 t/d	new	2016
Zafaran	Bushehr Petchem Co.	Assaluyeh	2	granule	800 t/d	new	2017
Zafaran	Persian Gulf Star	Bandar Abbas	2	granule	720 t/d	new	2016
KAZAKHSTAN							
Sandvik Process Systems	Atyrau Refinery	Atyrau	2	pastille	175 t/d	new	2016
KUWAIT							
Enersul	KNPC	Mina al Ahmadi	5	granule	6,000 t/d	expansion	2017
MALAYSIA							
Enersul	RAPID	Pengerang, Johor	5	granule	2,000 t/d	new	2018
MEXICO							
Sandvik Process Systems	PEMEX	Coatzacoalcos	4	pastille	1,080 t/d	new	2017
OMAN							
Sandvik Process Systems	SOHAR Refinery	Liwa	3	pastille	300 t/d	new	2017

System manufacturer/ supplier	Operating company	Operating site	Units	Product type	Scheduled throughput	New project/ expansion	Scheduled
PAKISTAN							
Enersul	ARL	Rawalpindi	1	wet prill	100 t/d	new	2016
RUSSIA							
Enersul	Syzran Refinery	Samara	1	granule	350 t/d	expansion	2017
Sandvik Process Systems	Orsk Refinery	Orsk	2	pastille	200 t/d	new	2016
Sandvik Process Systems	TAIF-NK	Nizhnekamsk	1	pastille	100 t/d	new	2016
Sandvik Process Systems	MAVEG	n.a.	5	pastille	576 t/d	new	2018
SAUDI ARABIA							
Matrix PDM	Aramco	n.a.	1	prill	750 t/d	new	2017
Enersul	Aramco	Yanbu	2	prill	200 t/d	new	2017
SPAIN							
Enersul	Petroleos del Norte	Muskiz	1	granule	350 t/d	expansion	2017
Sandvik Process Systems	Repsol	Coruna	2	pastille	290 t/d	expansion	2017
Sandvik Process Systems	Repsol	Puertollano	4	pastille	520 t/d	expansion	2017
TURKEY							
Enersul	Aegean Refinery	Aliaga	3	granule	1,050 t/d	new	2017
TURKMENISTAN							
Sandvik Process Systems	Turkmengas	South Yolotan	1	pastille	400 t/d	expansion	2016
VIETNAM							
Enersul	Nghi Son Refinery	Nghi Son	3	granule	1,380 t/d	new	2017

SOGAT 2017

PHOTO: PROCHASSON FREDERIC / SHUTTERSTOCK.COM

A report on proceedings at the 2017 Sour Oil and Gas Advanced Technology (SOGAT) conference, which returned to Abu Dhabi's Beach Rotana Hotel from March 26th-30th this year.

Above: View of the Abu Dhabi skyline at sunset, United Arab Emirates.

The Sour Oil and Gas Advanced Technology conference is now 13 years old, and during that time the amount of sour gas being extracted and processed in the Gulf region has only continued to increase, with its home base, Abu Dhabi, now being the site of some of the largest and sourest gas processing complexes in the world. As usual, the conference ranged over carbon dioxide issues and CO_2 capture, as well as some of the more upstream issues with sour gas production and processing, and included a number of workshops before the beginning of the conference proper, but the papers detailed here are those of greatest interest to a sulphur recovery audience.

In the opening session, which looked at some of the uncertainties which can often attend a sour gas project, Alessandro Buonomini of KT-Kinetics Technology shared some design work KT have been doing for a new sour (4.3% H_2S) gas field development in Egypt, which will include four 26 t/d sulphur recovery units. The field was only discovered two years ago, and exploration was still occurring during the design phase, complicating expectations of sour gas flow rates, while SRU efficiency was set at >99.9% and SO_2 emissions at less than 150 mg/m³. The tight project timescale (start-up is this year) led to a focus on modularisation, while the KT Multipurpose Absorber was used to ensure the required H_2S level of <10ppmw. BTX destruction was assured by fuel gas co-firing.

Pavan Chilukuri of Shell also dealt with planning for uncertainties in sour gas composition, here using a multiple-train approach which allows scale-up or -down. Even where BTX and mercaptan levels are not known, Shell's *Sulfinol* process can handle a wide variance, while *Cansolv* tail gas treatment can deal with stringent emissions specifications of <150mg/normal m³ SO_2.

The last paper of the session, by Jan Klok of Paquell, described *Thiopaq SQ* – his company's new upgrade to the *Thiopaq O&G* process, which uses H_2S-oxidising

bacteria to catalyse the oxidation to sulphur – this process is described in more detail elsewhere in this issue.

Energy efficiency

A short session on Tuesday morning looked at energy efficiency in sour gas processing. Max Shirazi of Energy Recovery reported on an installation of his firms IsoBoost turbocharger system within the amine system of a large scale sour gas processing station in Saudi Arabia. The plant has five Claus processing trains with amine-based acid gas recovery systems. The IsoBoost uses the energy of the rich amine solution to pump lean amine, with the pressure differential driving the turbocharger, preventing back-contamination, and in so doing reduces the energy duty requirement for amine pumps by 6.3MW, leading to energy savings of $55,000/year and CO_2 emissions reduction of 38,700 t/a. Mean time to failure is calculated at 10 years, he said, compared to around 3 for a centrifugal pump.

Saqqib Sajjad of Gasco discussed the results of a benchmarking scheme which had been carried out for the company's gas sweetening units, including establishing and measuring energy performance indicators (EPIs) at 17 SRUs across three sites – Bab, Habshan and Shah. Measuring actual performance against potential room for improvement allowed the identification of areas for implementation or further evaluation, on a case by case basis. Following the successful conclusion of the project, Adnoc has also decided to continue benchmarking performance on an annual basis and extend it to other companies within the group.

Process safety

In the session on process safety, Al Hosn Gas gave a presentation on managing process safety in sour gas operations, discussing their process safety management framework, comprising risk-based inspection, reliability-centred maintenance, and instrumented protection functions to try and achieve an individual risk level of a serious occurrence of 1 in 100,000, below the 1 in 50,000 level typical in industry.

When large concentrations of H_2S are present, the possibility of permeation through respirator materials becomes a potential issue. Mohammed Elagrab of MSA Safety discussed the fact that conventional testing of self-contained breathing apparatus does not test for this and so stated protection factors cannot be relied upon. Material selection becomes crucial, and he demonstrated how levels of 2ppm H_2S inside a mask/hood could be achieved even with a 25% external H_2S concentration.

Emissions reduction

Companies are having to meet ever more stringent standards as regards emissions these days, and in particular Shell Global Solutions highlighted the extremely tough new World Bank standards on SO_2 emissions of 50-150 mg/Nm³ for refiners and gas plant operators. This may necessitate re-thinking existing tail gas treatment systems, and Shell showcased their Cansolv TGT+ system as well as the Thiopaq O&G and SCOT Ultra configurations, all capable of meeting such demanding targets.

> **"Companies are having to meet ever more stringent standards as regards emissions.**

The World Bank has set a target of zero routine flaring by 2030, and as part of this initiative Gasco decided to introduce flare gas recovery systems for the hydrocarbon flares at its A, B and C plants. The initial study on the project began in 2008, from which a front end engineering design concept was put together, and the project finally implemented by 2013. Actual recovery in 2015-16 was 5.84 million scf/day, amounting to around $15 million per year in terms of fuel gas saved, at an equivalent cost of $2.60/MMBt, in addition to the CO_2 emissions reduction.

Dow Chemical has a new class of amine solvents, *UCARSOL*, for amine tail gas treatment, which offer benefits compared to MDEA in sulphur removal in high temperature environments. The paper, presented by Badar al Saadi of Dow, detailed field results from installation at CNOOC's refinery at Shanghai in China, where emissions limits on SO_2 are set to come down in July this year from 960 mg/Nm³ to 100 mg/Nm³. The results showed that the solvents reduced sulphur emissions by 60-75% at 40°C, and would allow the refinery to meet the new more stringent emissions limits below lean amine temperatures of 42°C. Work is now progressing on further optimising the solvents under real world operating conditions.

Gas treatment

The UAE University has put its mind to designing a gas analyser for continuous monitoring of H_2S in gas streams. The patented process is based on absorbing hydrogen sulphide into an alkaline solution, and then oxidising the absorbed sulphide ions with hydrogen peroxide. The process is strongly exothermic, and the temperature change is a reliable indicator of the amount of H_2S present. The current iteration of the process features a more compact and portable design with an improved detector, with faster and more sensitive response.

ExxonMobil has developed a new process for acid gas removal and dehydration of a process gas flow which it calls *cMIST* (compact mass transfer and in-line separation), replacing existing contactors and feed gas scrubbers. A mixer introduces a well-dispersed liquid flow into the gas to produce small droplets with a high surface area for absorption, followed by an in-line separator. The process is then repeated in a second stage. The whole apparatus has lower cost and weight than existing systems. The first application has used glycol in a dehydration system in Oklahoma, but an amine-based system for selective H_2S removal started up in March at the XTO Teague gas plant.

Treating ultra-sour gas (>20% H_2S) brings with it extra operating issues. Fluor presented is experiences at a recent installation using Huntsman's diglycolamine (DGA) as an absorber. Although the actual H_2S concentration turned out to be 25% – 2% higher than the design value – virtually all CO_2, H_2S and COS was absorbed, and >99% of mercaptans.

In Greece, the Thessalonika refinery is expanding its output from 70,000 bbl/d to 100,000 bbl/d. Siirtec Nigi has been involved with the refinery in developing a parallel expansion plan for the sulphur recovery section and amine unit to a target of 50 t/d of recovered sulphur. Process simulator results for modelling the upgraded system were presented at a previous conference, but this time Siirtec Nigi were able to show real operating data at increased loads which verified the modelling predictions.

Operating issues

C Balasubramanian of Gasco reported on an issue the company had experienced at Habshan V a year after commissioning, whereby ammonium salts were discovered in the sour water stripper overhead condenser piping, and up to 4% ammonia levels in the SWS reflux water. The source of the ammonia was theorised to be from the reaction of hydrogen and nitrogen in the hydrogenation reactor over a CoMo catalyst, and the amine regenerator, which requires ammonium sulphate addition to maintain the heat stable salt concentration. It was decided to divert the dirty SWS overhead gas to the SRU acid gas feed, to enable ammonia destruction in the Claus furnace.

Inshan Mohammed of Sulphur Recovery Engineering presented three case studies on SRU failures, including apparent catalyst deactivation in the first converter (actually a by-pass due to poor internal design), reduced recovery efficiency due to poor amine unit operation, and lower than expected COS and CS_2 hydrolysis rates for a titania catalyst.

Oxygen enrichment can increase SRU capacity, but care must be taken when exposing tube sheet linings to increased temperatures. Industrial Ceramics' Domenica Misale-Lyttle presented a case study of boiler tube failure where CFD modelling had showed the heat flux in the first metre of the tube had been 10% higher than recommended limits.

Qatar's Dolphin Energy reported on carryover of catalyst from a fixed catalyst bed sulphur degassing system designed to remove polysulphides prior to sulphur storage. Degassed liquid sulphur overflows a weir in the upper part of the degassing column and is routed to a sulphur pit via a liquid seal, and catalyst has been found in the seal and pit, and necessitated frequent catalyst replacement. It was found that the action was inherent to the degassing process being used, and catalyst loss remained high even with the installation of screens, and while entrainment has not affected the degassing performance or quality of the sulphur, a replacement degassing system is now under study.

Dolphin also gave a presentation on their operating experiences with sour water stripping, including problems such as unstable operation, an oily sludge causing clogging of the filter and reboiler, exceeding of H_2S levels in the stripped water, and corrosion in the stripping section of the column and reboiler. The sour water is a mix of quench water from the SRU and produced water, and the latter was found to be notably acidic (pH 3.5-4), leading the mixed water to be acidic even though the quench water is alkaline. The sludge is caused by oil getting into the water due to a faulty separator. It is now planned to divert the oily streams to an off-spec tank, and to re-route sour water from the stripper feed drum to the sour water storage tank, which should feed the stripper, with EDTA and caustic soda added to raise the pH to 6 to avoid corrosion issues.

Gasco has experienced vibration issues in the superheater region of four SRU incinerators which has caused some damage to refractory, welds and insulation. Analysis has concluded that vortices are formed in the burner region due to improper mixing of combustion gases, causing pressure fluctuations. A choke ring installed inside the incinerator was found to be a more cost-effective solution than a full burner replacement.

Finally, KT-Kinetics Technology showcased their SA-SRU supervisory analytics tool, a digital platform designed to bring SRU operators the benefits of KT's specialist knowledge on process, engineering and operation, using simulations which can plug in basic data and process constraints and produced a detailed picture of the operation of the plant which may not always be easy to visualise from plant data gathered from distributed control systems.

Recent innovations in acid equipment

The current focus of sulphuric acid plant technology providers is in the reduction of plant emissions, the development of equipment with better performance and reliability and the use of better materials of construction. This article focuses on recent innovations and the latest high performance sulphuric acid equipment from Chemetics and NORAM Engineering.

Chemetics' innovative equipment designs

Sulphuric acid plants deal with highly aggressive chemicals (SO_2 and H_2SO_4) which put a lot of stress on its plant equipment. The majority of operating and maintenance problems in sulphuric acid plants were historically easy to identify. Typically, they could be found on almost any acid plant after several years of operation. Operators of sulphuric acid plants always try to seek better technology that is characterised by the following criteria:

- A capability to comply with and often exceed all statutory environmental regulations;
- A self-evident potential for low maintenance and high reliability;
- A capability to achieve enhanced energy utilisation;
- Equipment that is cost competitive;
- Equipment that has designs that allow simple installations or retrofits.

Chemetics' solution to these challenges has been to eliminate many of these deficiencies with better process and mechanical equipment design, often incorporating superior materials of construction. The goal is to provide plant operators with the reliability, performance and products to meet the latest environmental and market conditions.

Chemetics' equipment designs have been continuously improved during 40+ years of plant experience to eliminate, as much as possible, the recurring maintenance problems associated with the traditional designs of sulphuric acid plants. These speciality items of proprietary equipment are now in themselves an important aspect of Chemetics' business, both in new sulphuric acid plants and also in retrofit applications.

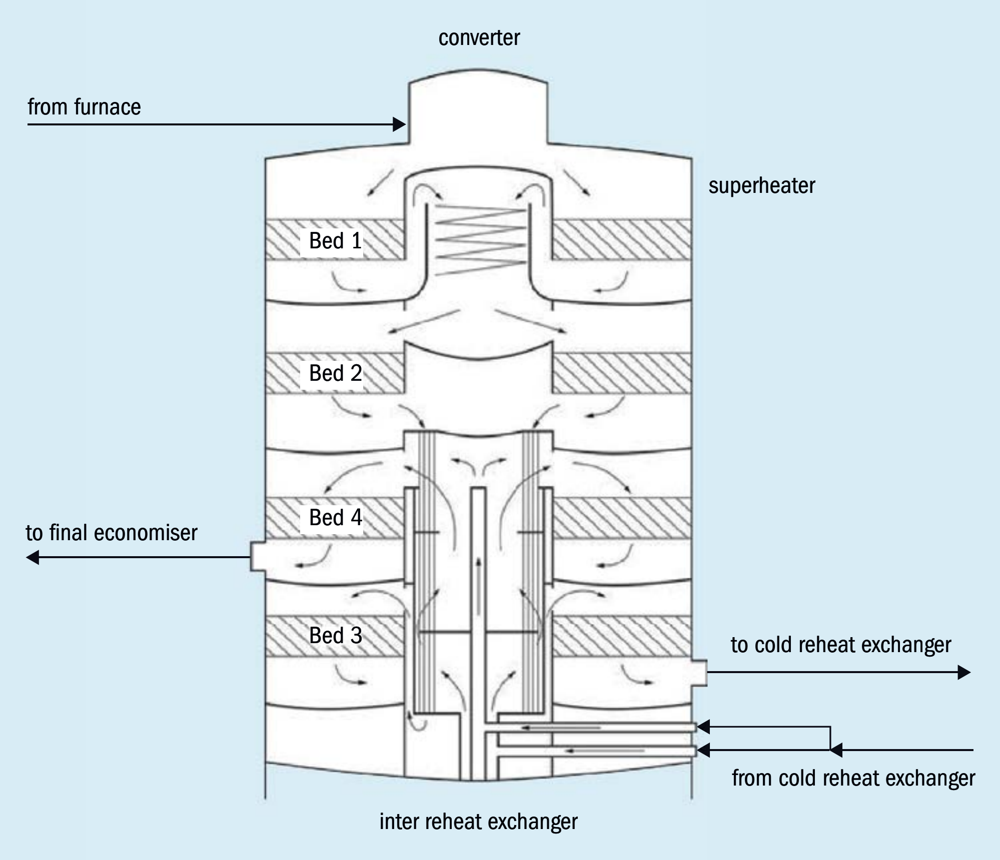
Adding to the features and benefits of modern sulphuric acid equipment, Chemetics recent innovations in sulphuric acid equipment allow acid plant operators to minimise the amount of work to be done in a hazardous environment while reducing the installation and maintenance time and costs.

Modular converter

The converter is the focal point of the sulphuric acid process. It is this vessel which contains the series of catalyst beds required to convert the sulphur dioxide gas to sulphur trioxide. The gas flows in series through these beds with intermediate cooling between each of them. Most modern double absorption processes require four (or more) catalyst beds.

Until 1980, when Chemetics introduced the first all stainless steel converter, this

Fig 1: **Chemetics converter with internal superheater and gas exchanger**



Source: Chemetics

PHOTO: CHEMETICS

Fig. 2: Prefabricated converter modules.

PHOTO: CHEMETICS

Fig. 3: Converter modules assembly in-field.

PHOTO: CHEMETICS

Fig. 4: Complete SARAMET® alloy acid tower.

PHOTO: CHEMETICS

Fig. 5: SARAMET® acid towers lifted into position.

vessel was traditionally manufactured from brick lined carbon steel and cast iron. Although many hundreds of these conventional units are installed around the world and are still in use today, most have caused the owners significant operating and maintenance problems.

Chemetics' design can incorporate internal gas exchangers and superheaters inside the core of the converter, which eliminates the hot gas ducting between beds 1 and 2, which is well known to be a continual maintenance problem on many plants caused by very high gas and metal temperatures. (Fig. 1).

Traditionally, converters that are too large to be shipped fully fabricated are built on-site using a "stick built" or "knock down" approach where plates are cut, bevelled and rolled remotely in a shop and welded together piece by piece on site. For large converters or retrofit situations, the time and labour required on site to complete the erection of a new converter can be four to six months with 50+ personnel working two shifts, six days a week. The time of fabrication at site has substantial risk associated with it due to the risks of site weather conditions as well as availability of skilled welders and fitters local to the plant site.

Since the 2000s, Chemetics started to supply virtually all of its stainless converters in a modular form to minimise field construction. The converter is shipped to site as prefabricated modules which are then assembled on-site. This method greatly reduces construction time from four to six months (for a conventional "knock down" build) to eight to ten weeks. Typically the installation can be accomplished by a single team of eight to ten workers in one shift of five days a week solely working during daylight hours. This unique approach also improved the overall quality of the construction since the majority of the welding and fitting was completed off-site in a fabrication shop under ideal conditions (Figs 2 and 3).

Alloy acid towers

With the introduction of silicon containing stainless steel such as Saramet® in hot strong sulphuric acid service, these alloys have been replacing the traditional standard of ductile iron acid piping, and more recently, in certain acid tower and acid cooler applications.

In retrofit situations when the shutdown time is very short, using alloy acid towers to replace existing brick-lined acid towers can be an attractive solution. Alloy towers have the advantage of allowing prefabrication of the entire tower or modules of the tower including internals off site. If the overall dimensions of the replacement tower are within the shipping envelope of ground transportation then the tower can be shipped to site in a single piece without further field assembly. If the shipping limitations prevent shipping the tower in a single piece, a modular approach can be done which allows quick and simple field assembly of the tower at site. Once the towers are lifted into position the tower packing and acid distributors can be immediately installed (Figs 4 and 5). This eliminates the premium cost and additional brick settling time required when using specialist contractors to complete the acid bricking installation on-site.

PHOTO: CHEMETICS

Fig. 6: Chemetics ISO-FLOW™ dstributors with SWIFT-LOCK™.

PHOTO: CHEMETICS

Fig. 7: Chemetics SWIFT-LOCK™ technology for trough distributors.

Acid distributors

The acid distributor in the acid tower provides uniform distribution of acid into the packing section. It is critical that the distributor reliably distributes acid to the entire cross sectional area of the packing. Common issues such as blocked downcomer tubes, unequal flow due to gas channelling, and/or uneven level of distributors can lead to poor SO_3/H_2O absorption which ultimately leads to accelerated corrosion in downstream equipment or high stack emissions.

Since their introduction in 1982, Chemetics' acid distributors have been fabricated from SARAMET® austenitic stainless steel. This material is easily welded and has demonstrated superior corrosion and erosion resistant properties in strong sulphuric acid service. The Chemetics' distributors provide uniform acid tower irrigation thanks to a high downcomer tube density, a stable acid level inside the trough made possible by the patented calming plate design, and individual tube orifice flow control. The ISO-FLOW™ construction is not sensitive to acid inlet velocities or trough levelling and is therefore more forgiving than overflow weir style designs. The calming plates incorporate filter screens that are easy to clean and prevent any debris from entering the acid distribution tubes making this design resistant to suspended solids, like packing chips and mortar pieces. In the event that a tube gets obstructed, the blocked tube would be very easy to spot thanks to the tube plate design that offers a visual inspection air-gap between the tube bundle and the trough plate. Liquid would overflow through this gap allowing immediate identification and rectification by maintenance staff during plant start-up after a maintenance shut down. The internal filters prevent plugging of downcomers during normal operation.

Chemetics continuously improves its proprietary equipment designs. As a result, some enhancements have been recently implemented into the ISO-FLOW™ trough distributors:

- Improved ease of assembly and reduced shutdown time for installation, by eliminating all field installed hardware and reducing the site assembly parts to the fewest available in the industry. This was achieved with Chemetics' proprietary SWIFT-LOCK™ tube attachment system (Figs 6 and 7).
- The Chemetics tube bundles already reduced the amount of tubes and subassemblies to be installed to an optimal minimum, but they previously required extensive hardware attachment during installation. The bundles are now assembled using the proprietary SWIFT-LOCK™ mechanism. This ensures rapid and easy installation using 95% less hardware than the previous design, none of which requires field installation.
- The distributor assembly time required is reduced by 50% and even more for acid contaminated cases.
- All tube bundle attachment parts now ship assembled to the trough itself. Once the trough has been set in the tower, all that is needed is sliding the tube bundles into place, then revolving the rotating tab for the tubes to be properly set and aligned.

PHOTO: CHEMETICS

Fig. 8: Chemetics radial tube gas exchanger.

Segmental tube in gas-exchangers

As acid plant world scale size continues to increase, the demand for larger gas-gas heat exchangers continues to rise. In particular, in many retrofit applications it is desirable to reduce plant pressure drop by replacing older "cross-flow" style heat exchangers configured in series, with a single low pressure drop radial tube layout heat exchanger. Even though a modern gas exchanger (e.g. Chemetics patented radial tube layout design) is significantly more efficient than traditional designs, the increasing plant size as well as the push for lower

PHOTO: CHEMETICS

Fig. 9: Modular gas-gas heat exchanger fabrication.

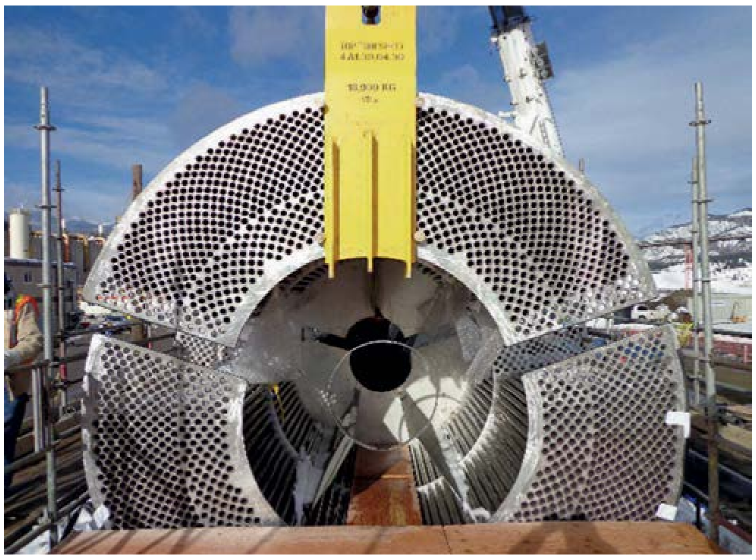


PHOTO: CHEMETICS

Fig. 10: Assembly of segmental tube bundle exchanger on site.

autothermal design points, results in very large exchangers that are in excess of 200 tonnes in weight. Traditionally for very large gas exchangers the typical approach would be to fabricate the exchanger in field or ship an exchanger with partially loaded tubes, with the balance of tubes loaded on site. This approach of field fabrication results in the majority of the critical tube to tubesheet welds being done in the field in non-ideal environmental conditions. Additionally the length of time for field fabrication and lack of availability of skilled trades for this work on site often makes the cost prohibitive.

To overcome these issues of site fabrication of large gas exchangers, Chemetics has developed a method to modularise the tube bundle into segments which can be assembled easily and safely on site (Figs 9 and 10). The plan is adaptable depending on the precise shipping windows available for each site. As an extreme circumstance Chemetics followed this methodology to build six gas-gas heat exchangers for a project for a 3,800 t/d sulphuric acid plant where the shipping envelope was limited to standard 12 m shipping containers.

To modularise a Chemetics gas exchanger, exchanger bundle pieces are designed and built with integral shipping saddles. The largest saddle is used for a cradle for field assembly of the bundle. Modular bundle sections are assembled together in the horizontal position in the field taking care to ensure tubesheet and baffle integrity and alignment. Once the bundle is complete the bottom and top vestibules are added to the tube bundle and the assembled unit is installed on the gas exchanger foundation in the vertical position. The shell including expansion joints are then installed on the outside of the bundle to complete the installation. With this methodology approximately 85% of the gas exchanger assembly time and 90% of the critical welding is done in a shop environment ensuring good quality. The remaining welding and fitting can be accomplished by a small team of experienced fitters and welders.

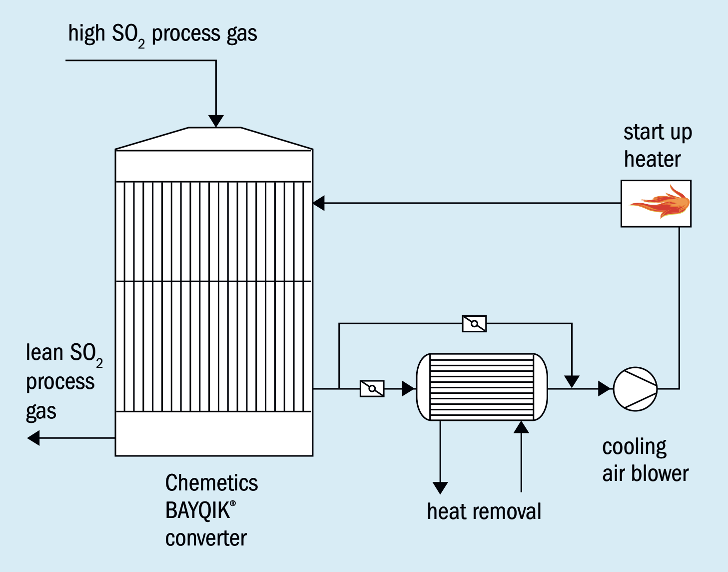
BAYQIK® pseudo isothermal reactor

With increasing use of oxygen enrichment and advancements in smelter technology, new non-ferrous smelters are producing stronger SO_2 (15-25%) gas at the converter inlet. It is desirable to reduce the amount of air dilution to reduce the overall gas flow to the acid plant. However, a conventional acid plant (double contact, double absorption) is limited to 12-13% SO_2 at the converter inlet to keep the gas temperature leaving the first pass of the catalyst bed

PHOTO: CHEMETICS

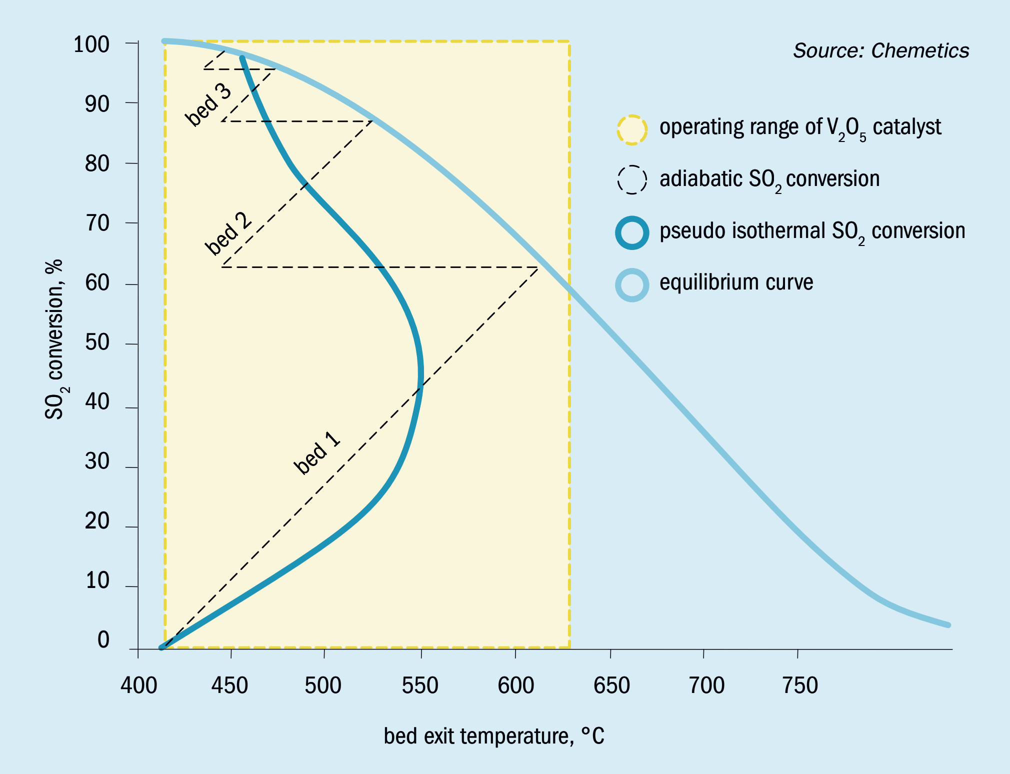
Fig. 11: BAYQIK® add-on installation has been operating since 2009.

Fig 12: **Chemetics BAYQIK® system**



Source: Chemetics

Fig 13: **SO_2 conversion curve of conventional adiabatic process vs pseudo-isothermal process**



below the thermal stability of vanadium based catalyst (~630°C).

To counteract this limitation, Chemetics offers two solutions: the Chemetics High Strength (CHS™) process and the Chemetics Pseudo-Isothermal process using BAYQIK® reactor technology, which combines a gas exchanger and catalyst in a single vessel. In short, CHS™ is designed for multiple SO_2 off gas sources or smelter off gas that is high in SO_2 but deficient in oxygen, whereas BAYQIK® reactor technology is most valuable in treating a single strong gas source.

On August 26, 2016, Chemetics acquired all patents and know-how for the BAYQIK® converter technology from Bayer AG. BAYQIK® converter technology is a commercially proven pseudo-isothermal reactor system capable of converting high strength (up to 50%) SO_2 gas without diluting the gas with air or recycling process gas. The first commercial installation in Germany has been operating continuously for more than eight years (Fig. 11) and the second larger plant was commissioned in February 2017.

The Chemetics BAYQIK® converter is the only commercially available isothermal converter system for SO_2 oxidation. The patented tubular converter uses conventional vanadium based catalysts with SO_2 gas flows through the tubes. Continuous removal of reaction heat on the shell side allows the process temperature to be controlled within the operating limit of the catalyst. Energy recovered from the heat removal system can be used for preheating the process gas and for generating high pressure steam. (Fig. 12) In addition, the pseudo isothermal process operates further away from the equilibrium curve than a traditional multi-pass adiabatic process as shown in Fig. 13. This results in lower overall catalyst loading and significantly higher SO_2 conversion in a single pass.

NORAM high performance equipment

NORAM Engineering focuses on upgrading sulphur burning, metallurgical and acid regeneration sulphuric acid plants. Each plant has unique process, mechanical, layout, schedule and budgetary constraints that require significant engineering and ingenuity.

New technologies are usually implemented in new acid plants but may also be retrofitted in existing acid plants requiring equipment replacement or performance upgrades.

SX high-silicon alloy equipment

High silicon alloys such as NORAM SX™ have low corrosion rates in hot sulphuric acid and can be used in the manufacture of acid coolers, acid piping, tanks, acid towers and acid distributors. Key advantages include: low weight, no requirement for brick/Teflon lining, no need for anodic protection and faster installation. This material is particularly attractive to quickly replace brick-lined towers and tanks. Large equipment such as acid towers can be assembled on site and crane-lifted in a short plant shutdown.

Acid towers

NORAM offers both brick-lined acid towers and NORAM SX™ alloy towers.

In the NORAM brick-lined acid tower design, a dished bottom is used for heavy metal wall thickness to provide a rigid sup-

PHOTO: NORAM

Fig. 14: NORAM SX™ acid towers.

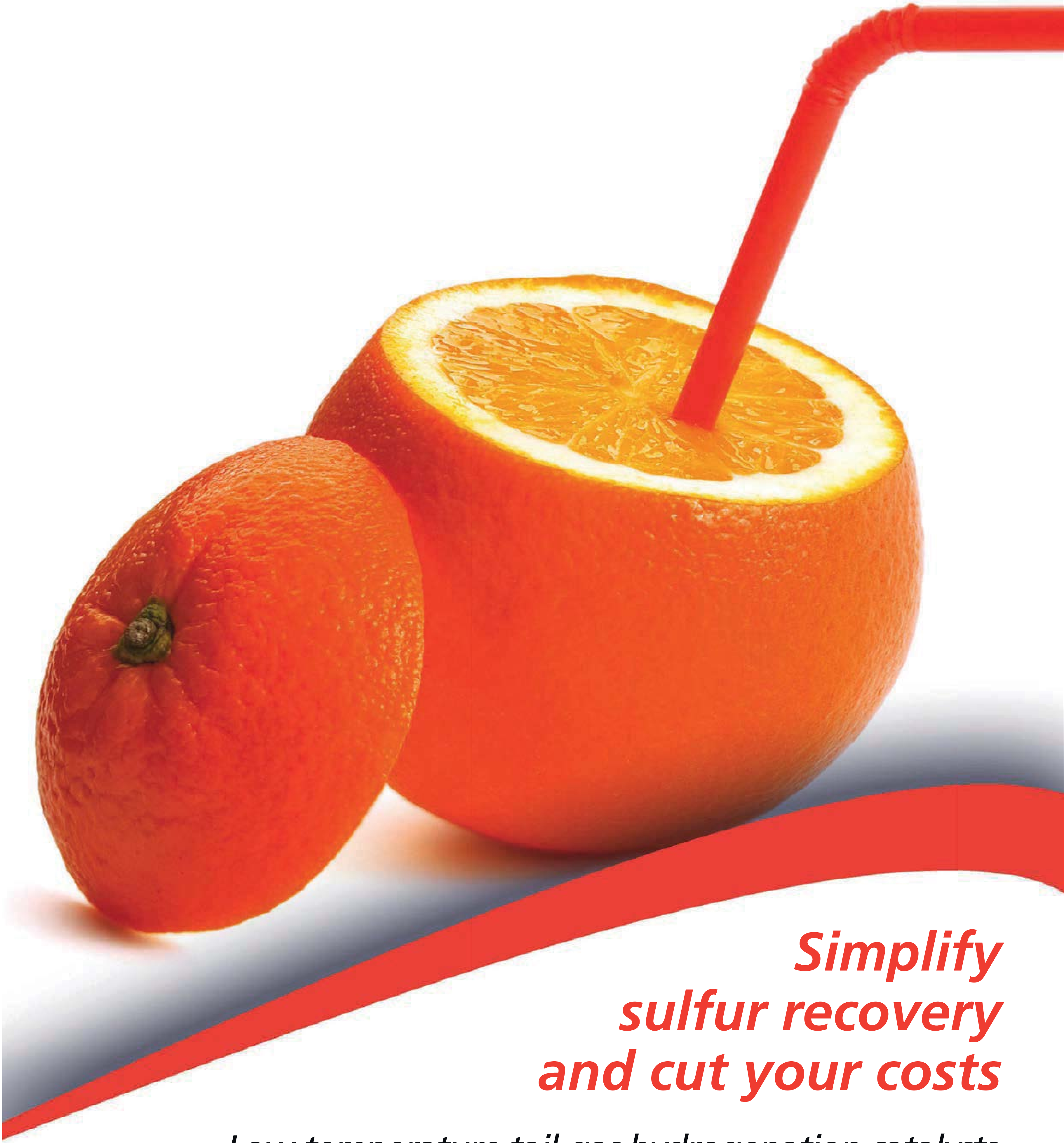


Fig. 15: Low pressure drop acid packing.

Fig. 16: NORAM SX™ *acid cooler.*

port for the brick. This shape maintains the brick under compression, a state where this material has excellent strength characteristics. The bottom outlet nozzle for the acid is fitted with a special alloy liner and is sized to be self-venting, thus minimising gas entrainment. The gas inlet nozzle is brick-lined and sloped to prevent back-flow of acid spray into the duct. The packing support is provided by a self-supporting dome with an open area of about 60%. State-of-the-art brick lining is used constructed from ASTM Type III acid proof brick, backed by special acid resistant membranes and lining systems (e.g. Teflon, Rhepanol or others).

In the NORAM SX™ design (see Fig. 14), compared to traditional brick-lined carbon steel, alloy vessels offer several advantages, particularly for replacement of towers and pump tanks. The reduced tower diameter or optional increased capacity/reduced pressure drop is an attractive benefit. Other benefits of alloy towers include:

- alloy vessels are considerably lighter, with smaller footprint reducing the cost for foundations and facilitating installation;
- overall installation time is reduced circumventing the time required for brick lining;
- small and medium size towers and tanks can be shop fabricated and shipped to site reducing installation work and shutdown time to a minimum;
- maintenance, service and inspection is made considerably easier.

Acid towers can be upgraded for higher reliability. Upgrades can include the replacement of corroded/fouled equipment and replacement of distributers prone to plugging with distributors that are easy to clean. Strong low-chip ceramic packing can also be used to reduce fouling.

The acid plant gas hydraulics can be debottlenecked by reducing the pressure drop of the acid towers. This can be achieved by using the following strategies:

- sizing the absorption tower diameter to minimise pressure drop. This requires calculations of the tower hydrodynamics;
- use of low pressure drop packing (see Fig. 15).

NORAM HP™ saddle packing has a proven semi-toroidal saddle shape, which provides random interlocking and uniform void space. This conventional shape has been modified to reduce pressure drop and promote mass transfer efficiency. NORAM HP™ packing has a pressure drop which is typically half of that of a conventional 3" saddle. The gas throughput in an existing acid tower can be conservatively increased by about 25%.

Acid coolers

An alternative to anodically protected acid coolers is NORAM SX™ acid coolers which have the following features:

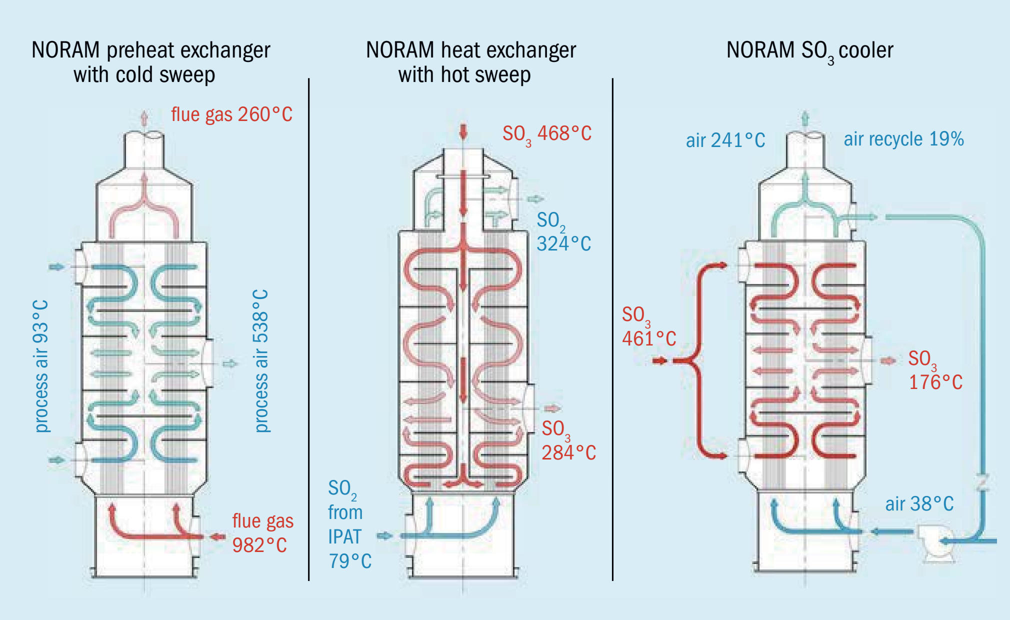
- lighter;
- smaller (can use higher acid velocities and higher heat transfer coefficients);
- do not require anodic protection;
- offer unlimited resistance to liquid acid erosion;
- lower installation time and cost.

Stainless steel SO_2 converters

Converter design requires considerable mechanical and materials engineering. The exothermic conversion of SO_2 to SO_3 is carried out in a series of catalyst beds in a converter. The process gas temperatures in the converter range from 380°C to 650°C. The converter has to deal with significant mechanical loads from catalyst weights, nozzle loads and gas pressure drop. The use of stainless steel results in lower equipment weights, better mechanical strength at high temperatures and increased resistance to corrosion. NORAM has developed design and manufacturing procedures which allow shop fabrication of converters in sections, shipment to site and field assembly. This approach enhances quality and minimised field erection time.

Key features of the NORAM stainless steel converter are:

Fig 17: **Heat exchanger with metal temperature control**



Source: NORAM

PHOTO: NORAM

Fig. 18: NORAM trough acid distributor prior to installation.

PHOTO: NORAM

Fig. 19: Acid distributor with external clean-out nozzles.

- all-welded stainless steel designs (typically made of stainless steel 304H, brick lining option available to increase thermal inertia);
- flexible catenary-shaped catalyst bed support plates;
- uniform gas flow distribution;
- high overall SO_2 conversion efficiency;
- rapid heat-up and cool down;
- no requirement for internal core sections;
- lower thermal inertia – allows for faster start-ups.

To date, no NORAM stainless steel converter is known to have needed replacement. The first NORAM stainless steel converter has been operating for more than 25 years.

The project cost of a converter replacement in the same location is much lower (often 30 to 40% less expensive) compared to installing in a new location, as existing foundations, ducting, platforms etc. can be reused.

Split flow gas-gas heat exchangers

The biggest consumer of energy in the acid plant is the main air blower. To reduce its power consumption, it is desirable to minimise plant pressure drop by using state of the art equipment. The benefits of radial flow gas-gas heat exchangers for the large volumetric flows encountered in sulphuric acid plants are well known in the industry. Radial flow heat exchangers can provide lower pressure drops and require less heat transfer area than conventional single and double segmental exchangers.

NORAM radial flow (RF™) split flow (SF™) heat exchanger designs offer several advantages in certain applications that can result in both equipment cost savings and operational cost savings.

The split flow design is helping to significantly reduce shortcomings of sulphuric acid plant gas-gas heat exchangers with countercurrent flow arrangement with regard to metal temperature that can be either too cold or too hot.

Split flow heat exchangers, which are not necessarily more expensive compared to true countercurrent exchangers, can bring significant economic benefits through better performance, higher energy recovery, lower pressure drop build-up, longer life expectancy and less maintenance.

The patented split flow gas-gas heat exchanger design divides the gas to one side of the exchanger into two parts. One part is used to sweep the "troubled" tube sheet and eliminate the operational problems that otherwise show up here.

The SF™ design concept has been used in three types of gas exchangers (Fig. 17):

- preheat exchangers;
- cold interpass exchangers;
- SO_3 coolers.

In a preheat exchanger the "cold sweep" lowers the tube wall temperature in the hottest spot where hot gas from the furnace enters the tubes. This "cold sweep" increases the overall fuel efficiency and may be used to design a smaller, less expensive preheat furnace, air blower and heat exchanger solution.

For a cold or cold interpass exchanger the "hot sweep" raises the tube wall temperature in the coldest spot where cold, acid saturated gas enters the tubes. The SF™ exchanger operates well above the acid dew point, and reduces the rate of sulphate fouling and corrosion significantly.

With a SO_3 cooler the "hot sweep" raises the tube wall temperature in the coldest spot where SO_3-rich gas is leaving the tubes. This design may reduce the amount of air recirculation and eliminates condensation/solidification of SO_3, reduces the rate of sulphate fouling and results in a compact heat exchanger.

Acid distributors

Uniform acid distribution is important to achieve the required performance in acid towers. This prevents gas bypassing and H_2O (in drying towers) and SO_3 (in interpass and final towers) slippage. For this reason, it is key to install and maintain adequate acid distributors. Packed towers produce a small amount of chips coming from the bricking and the ceramic packing. These chips can plug acid distributors. Different mechanical designs for acid distributors have been developed to provide even acid distribution with simple to maintain units.

The NORAM SX™ pipe acid distributor is a cost effective design with very reliable performance. An acid header and pipe arms with orifices distributes the acid on top of the packing. Attention is paid to minimise gas velocity and acid spray formation. The design permits a very easy installation and is particularly suitable for replacement of old acid distributors.

The NORAM SX™ trough acid distributor (Fig. 18) is a high efficiency design with very uniform and well dispersed acid distribution. Troughs with evenly spaced downcomer tubes distribute the acid through gravity flow into the packing for optimum performance and minimal spray formation. The design prevents debris in the acid from obstructing the downcomer tubes and the acid flow in the troughs can be inspected during operation. It is particularly suitable for large and high performance towers.

The SMART™ acid distributor (Fig. 19) is a proprietary, multipurpose design comprised of radial pipes equipped with FEP downcomer tubes. The design provides a flexible, uniform acid flow, minimising gas flow restriction and acid spray formation. Particularly suitable for new towers where external inspection ports can allow inspection and cleaning of the distributor without tower entry.

The modular approach for SRUs

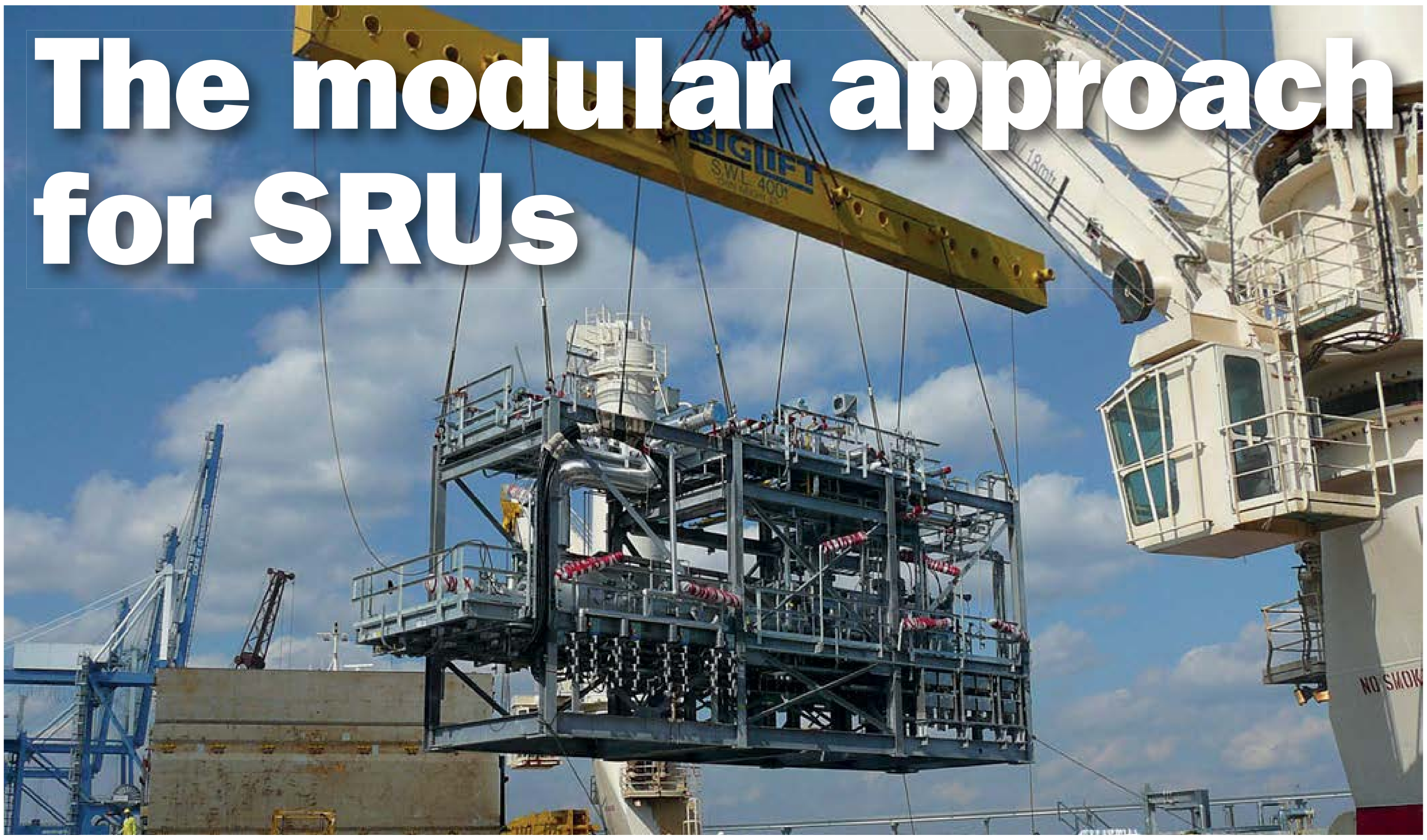


PHOTO: JACOBS COMPRIMO SULFUR SOLUTIONS

Modularisation provides a solution to many specific challenges faced by the oil and gas industry. This article discusses the benefits of modular construction of sulphur recovery units (SRUs), what makes modular construction viable, and key factors to consider and follow when designing modular units. Highlights of recent modular SRU projects are also presented.

In recent years the modularisation of process units has become essential for harsh environments where there are limitations and significant delays to using the stick-built model. Sulphur recovery units (SRUs) are very amenable to modularisation and are commonly designed to be modularised. In general terms, modularisation involves designing and fabricating "sub-assemblies" (modules) of a process unit at a facility located away from the final location of the unit, then shipping, installing, and completing interconnections between modules at the site. Well-designed modular units can maintain many of the accessibility and maintainability advantages of stick-built units.

Key considerations to assure a successful modular project include:

- shipping constraints need to be researched and defined before commencing design work, for the entire route from shop to site;
- schedule of module fabrication and delivery sequence must be co-ordinated with site construction to optimise and minimise site resource requirements;
- a detailed division of responsibility (DOR) must be developed to define the roles and responsibilities of the engineer, module fabricator, equipment suppliers, and construction contractor.
- input and agreement on DOR to be obtained from all involved parties;
- define extent of items to be included on modules i.e. large vessels, towers, tanks, instruments, etc.;
- define items to be "shipped loose" – interconnecting piping, ladders, stairs, sensitive instruments, etc. for field installation;
- shop-fit of adjacent modules prior to shipping is highly recommended so any misalignment can be corrected prior to shipping;
- structural design must consider all loads (lifting, gravity, transport etc.) and may require larger members;
- module design requires more information early in the project schedule, i.e. weight of equipment, size of equipment, early finalisation of layout, etc.;
- engineer presence in fabrication shop is highly recommended – oversight, communication (RFIs), inspection.

The size and weight of equipment relative to the allowable dimensions and load limits that will be encountered in transporting modules from the fabrication shop to the site are key factors in the practicality of the modular approach.

In order to be suitable for a modular approach the project site location should be suitable for delivery of modules, i.e. a coastal or riverside location with close proximity to receive the vessels transporting the modules, or an in-land location with a suitable road system (avoiding bridges and overhead bridges) to allow for the transportation of modules via trucks or self-propelled modular transporters.

Truckable modules are typically up to 5 m wide by 4 m high by 22 m long where transportation logistics allow, taking into account roads, power lines, overpasses, existing facility limitations, as well as construction constraints. The sizes of super modules vary but typical values are 10 m wide by 11 m high by 37 m long where transportation logistics allow, taking into account water/dock access, open site flexibility as well as construction flexibility.

In the US, for example, SRUs with a capacity of up to 100 t/d of sulphur can typically be modularised and transported over public highways. Specific conditions for each unit need to be evaluated; in some cases higher capacity SRUs may be amenable to modularisation.

Modular design and construction benefits include the potential to reduce overall cost and schedule, improve quality and safety performance, and reduce the magnitude of the on-site construction effort. Along with the benefits come potential negatives including greater equipment and piping congestion, increased engineering and design costs, added logistical challenges, and the potential for far-reaching impacts if critical items are not delivered to the module fabrication shop according to schedule.

Modular construction offers advantages over stick-built construction when any of several conditions prevail locally at the plant site. Plants that are in remote locations may benefit greatly from the reduced number of site personnel and time on-site that can be realised from modularisation. Sites with extreme climate conditions that result in increased costs, decreased efficiency, weather delays, etc. can realise the value of modularisation.

Modular construction is normal practice in offshore applications and in cold climates e.g. in Canada, Russia, China, Alaska and parts of Europe and has also become popular for onshore projects.

In modular projects, site civil and foundation work can be performed in parallel with off-site module fabrication activities, and module foundation requirements are generally simpler, thereby yielding cost and schedule savings.

Fabricated modules can be scheduled to arrive just-in-time for site installation as soon as the respective civil work is completed, with minimal installation and inter-module connecting work. Minimising the number and interdependency of serially connected critical path activities at site will reduce overall project schedule risk. Increasing indoor work scope with workshops greatly minimises weather impact to welding and coating activities, reducing construction down time. Reducing outdoor and working at height activities will also improve construction efficiency and lower cost.

A modular approach will allow the project to tap into the resource pool(s) of the sub-contractor yard(s) / location(s), by utilising facilities (shelter workshops, warehouse, gantry cranes, radiographic testing RT bunkers, power, water, compressed air, etc.), manpower, equipment, expertise and strength which are readily available. Project control and flexibility is improved by minimising interfering activities at the site (RT, hydro-test, coating and hot work, civil and utility work, etc.).

Fabrication shops generally have experienced, skilled craft workers, established procedures and production techniques that enable high productivity relative to field labour. Labour relations are simplified or eliminated, and the risk of labour disputes and work disruptions is significantly reduced in modular construction. On large projects, competition for labourers at the project site may result in unduly inflated wage rates.

In some cases, the module provider is able to fabricate some of the equipment themselves in their yard which reduces the cost of shipping equipment, otherwise close co-ordination between the module fabricator and equipment supplier, and sometimes the licensor, is required.

The main characteristics of a modular fabrication yard can be summarised as follows:

- Capable of fast track modular fabrication with large warehouses, large structural piping and coating workshops, large erection area with high load bearing capacity, radiographic testing (RT) bunker, post weld heat treatment (PWHT) furnace, big tonnage gantry crane, tower cranes, mobile cranes, self-propelled modular transporter (SPMT), module weighing station, auto and semi-auto welding machines, computer numerical control (CNC) cutting machines, total stations, phased array ultrasonic testing (PAUT) machines, localised PWHT machines, etc.
- Experienced project, safety and quality management team, and skilled labour for structural, piping, electrical and instrumentation (E&I), coating, non-destructive testing (NDT) and scaffolding disciplines. Familiarity and experience with international codes and standards. Capable to communicate and prepare documentation in international languages.
- Detail design capacity to support clients when required for, pressure vessels, heat exchangers, process skids, tertiary structures, small piping, cable and cable tray routing, architectural/outfitting, etc.
- International procurement capability to buy non-long-lead and long-lead local and overseas material and equipment of various disciplines.
- Custom handling experience for preparation of duty-free material importation and module exportation.

A modular approach will also improve the overall project HSE and quality performance. More work scope performed by the module fabricator means more work is performed indoors, at ground level, at locations where safety and quality are more controllable. Improved security can also be expected due to guarded compounds and warehouses with closed-circuit television (CCTV), and damage to equipment and theft are less likely to happen.

While the above discussion is general in nature, specific SRU-related modular design and construction necessitates additional discussion. Foremost is the question of how to collect and handle the molten sulphur product, which is traditionally collected in a below-grade concrete pit after flowing through in-ground seal legs. An early project decision on the sulphur handling philosophy must be made – whether to follow the traditional approach or to forego excavation and collect and store molten sulphur entirely above grade level. Proven approaches to above grade collection and storage exist and can be implemented in a modular fashion; however some clients/owners have preferences that require the traditional approach. While the traditional approach is technically proven, it reduces the amount of off-site modular work that can be done. A key factor that can influence the decision is the quantity of molten sulphur storage required, which may necessitate site fabrication of either a large below grade pit or an above grade tank.

SRU equipment that is refractory-lined presents another critical decision point –

PHOTO: RATE

Fig. 1: RATE modular design for a sulphur recovery unit.

shop-installed or field-installed? The risks and benefits of each approach need to be evaluated and the best option selected. Refractory integrity is essential to safety and reliability, and should be the primary driver in making this decision.

Typical heights for TGTU towers range from 12 m for the quench tower to over 30 m for the regenerator. Considerable pre-dressing of towers with internals, platforms, ladders, and piping is common. Modularisation of towers would require the tower to be built into a supporting structure which could be shipped and set as a unit, as opposed to setting the tower on its own foundation with anchor bolts. A large crane would be needed for erection for both the stick-built or modular options.

Depending on the project, the stack height may be 46 m or more to promote dispersion of the plant effluent. For most projects, shipping limitations would force the stack to be fabricated and pre-dressed in sections, then assembled on site, necessitating a large crane for the erection.

RATE modular SRUs

RATE licenses sulphur and gas processing technologies, offering total sulphur management for upstream and downstream, offshore and onshore, from sour gas field developments, to gas plants, refineries, chemicals and petrochemicals, gasification and mining worldwide. Through these activities, RATE has been involved in the evaluation of many projects that have met the qualification for modular construction, such as:

- fast track schedule, desire for parallel civil and module fabrication activities;
- site with limited access to skilled manpower and specialist equipment, high cost for their mobilisation to site;
- harsh weather conditions with expectancy of low work efficiency at site;
- utility and labour accommodation constraints at remote site location;
- low expectancy of security at site from exposure to theft and unrest;
- desire for high quality welding and coating work;
- limited space at site location to allow direct erection of modules at site;
- limited access to material needed for direct erection of modules at site.

RATE has been able to overcome many challenges related to constructability of these facilities by having an excellent fabrication partner for modular construction. With their extensive experience and working in close partnership with RATE, units have been modularised such as the amine unit, dehydration unit, SWS, sulphur recovery and tail gas treating and incineration system.

Fig. 1 shows an example of RATE modular designs for the sulphur recovery and associated units.

Amec Foster Wheeler case study

Amec Foster Wheeler has broad experience working with module fabrication yards in the US and around the world and uses its experience in placing and managing module fabrication contracts with fabricators in many locations including the Far East, Europe, and US to offer the best value modular execution solution.

The following case study describes a recent modular SRU project executed by Amec Foster Wheeler. In this project, Amec Foster Wheeler designed and built a complete sulphur complex for a refinery in the US using partial modular construction. The complex included a sour gas absorber, sour LPG absorber, amine regeneration unit, sour water stripper, sulphur recovery unit, tail gas treating unit, incinerator and stack. The scope of work included process design, detailed engineering, procurement, module procurement, construction, commissioning, and start-up assistance.

Because of the high concentration of H_2S in many process pipelines within the SRU and TGTU, Amec Foster Wheeler strongly recommends minimising flanges in process piping. Modular design that includes flanges in H_2S-containing process lines at module boundaries is not recommended; field welds are used instead.

In the bidding stage, modular design and construction was selected based on the expectation of high labour cost and low labour availability on site due to simultaneous construction of a much larger project at the same refinery. The overall schedule was laid out so that civil work, pipe rack construction, foundation design and construction etc. could be carried out concurrent with engineering design during the autumn, followed by partial site demobilisation over the winter months. Equipment and material orders were placed in the June/July time frame, and a module fabricator was selected and kicked off in September. Equipment was delivered to the module shop during November, December, and January. Module fabrication was performed in a controlled indoor shop over the winter months, followed by shipment to the site beginning in late March. Over the road shipping of approximately 1,300 miles was accomplished, with a maximum module envelope of 4.25 m wide, 4.25 m high, and 12 m long. Maximum module weight was 120 t.

A total of 23 modules were fabricated, shipped, and set in place on site between April and July. The order of module fabrication and shipping was dictated by the construction plan to optimise handling of the modules on-site. Modularisation of equipment was maximised, with all equipment except towers, amine tanks, rich amine flash drum, incinerator/stack, sulphur pit, below grade amine and sour water collec-

PHOTO: AMEC FOSTER WHEELER

Fig. 2: View of modular installation, note lower module structure is covered by finished concrete.

PHOTO: AMEC FOSTER WHEELER

Fig. 3: Overhead view of finished sulpur complex.

tion sumps modularised. The main unit pipe rack was not designed in modular format. These items were not modularised due either to their size exceeding the maximum module shipping envelope or they were being set below finished grade.

To meet shipping envelope restrictions, modular units often become congested with limited maintenance access. One of the client's requirements on this project was to provide operator and maintenance access similar to what would be expected in a stick-built unit. To ease ingress and egress, eliminate limited-access areas below the lower skid, and provide an easy-to-clean grade level, the finished concrete level was high enough to cover the base supports of the lowest module (see Fig. 2). Because the concrete paving was installed to cover the top of the module structural steel, additional engineering and design was required to install equipment above the top of the module structural steel.

The completed sulphur complex is shown in Fig. 3.

Prosernat case study

Prosernat has experience with more than 450 modular units installed worldwide in the oil and gas industry, including successful applications for sulphur recovery.

The SmartSulf™ technology with its limited number of equipment items makes it well suited for projects requiring fast track modular delivery for sulphur recovery plants with high sulphur recoveries of up to 99.5%.

This case study describes a project for the delivery of a compact SRU with high sulphur recovery efficiency for an early production facility (EPF) in Kuwait.

The Jurassic gas field early production facilities involve the treatment of fairly sour feed gas streams, with each EPF phase requiring 2 x 100 t/d SRUs. SPETCO, build-operate-transfer (BOT) operator of one of the EPF phases, has selected Prosernat with its SmartSulf™ technology for the SRUs. The SmartSulf™ units will be completely modularised for easy and fast track site installation. Delivery of the project is scheduled for early 2018.

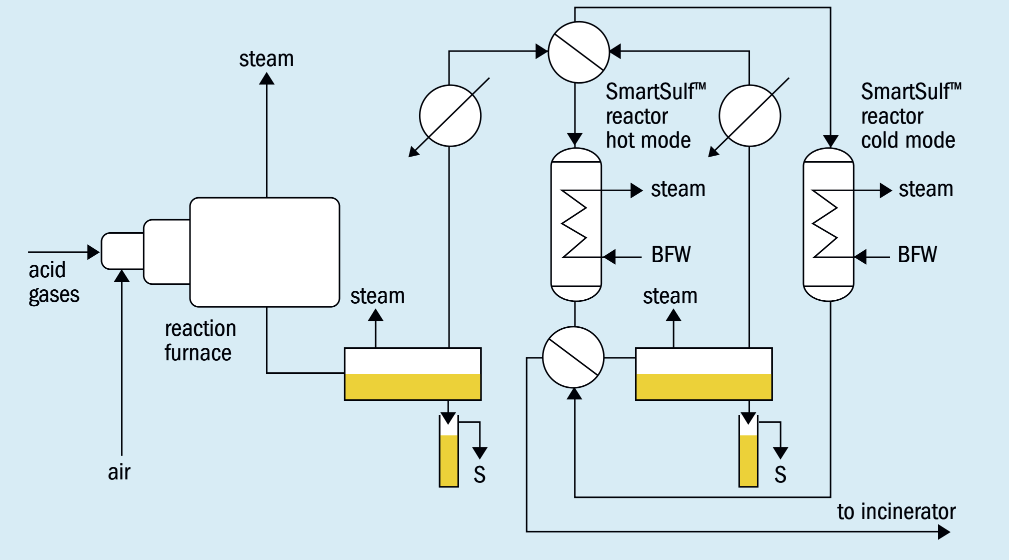
The key reasons for selecting Prosernat and its SmartSulf™ process for this EPF project were:

- the capacity of the process to meet local environmental regulation;
- the compactness of the process with a minimum amount of equipment items compared to other technologies;
- the low cost of this technology, compared to alternative Claus + tail gas treatment options;
- the capacity of Prosernat to supply the unit fully modularised within a tight timeframe;
- the capacity of Prosernat to support its customer for BOT projects through financing and continuous operational support.

Local environmental regulations require the SRUs to achieve an overall sulphur recovery of at least 99.4%. This level can be guaranteed with the SmartSulf™ process without the need for installation of any downstream tail gas treatment process. The concept of the SmartSulf™ process is based on the use of a two Claus catalytic stages but differs from conventional Claus by the fact that the catalytic reactors are operated under isothermal conditions and the second catalytic stage is operated under sub-dewpoint conditions in order to achieve much higher sulphur yields than in a conventional Claus process. This concept is shown in Fig. 4.

Acid gas is fed to the thermal section, similar to what is found in a conventional Claus design. After sulphur condensation and reheating, the tail gas from the thermal stage is fed to the first catalytic stage. Both catalytic reactors are equipped with an internal heat exchanger to control the temperature in the reactors. The heat of the Claus catalytic reaction is removed by circulating water counter-currently in the heat exchanger inside the reactor. The first catalytic reactor is operated at temperatures above the sulphur sub-dewpoint. However, by controlling the temperature at the outlet of the first reactor, higher catalytic conversions are achieved than in a conventional first stage Claus reactor. After sulphur condensation, the gas from the first reactor is fed to the second catalytic reactor. This reactor is operated at temperatures below the sulphur sub-dewpoint, thus achieving much higher conversions. Because the temperature is controlled to the outlet of the reactor the conversions achieved are in fact even higher than those obtained in conventional sub-dewpoint tail gas treatment processes. For a typical acid gas in a refinery overall sulphur recoveries are above 99.5%. In most cases, therefore, tail gas from the SmartSulf™ unit can be sent directly to the incinerator without the need for any downstream tail gas treatment unit. This is also the case for the early production facilities in Kuwait.

Fig 4: **Schematic of the SmartSulf™ process**



Source: Prosernat

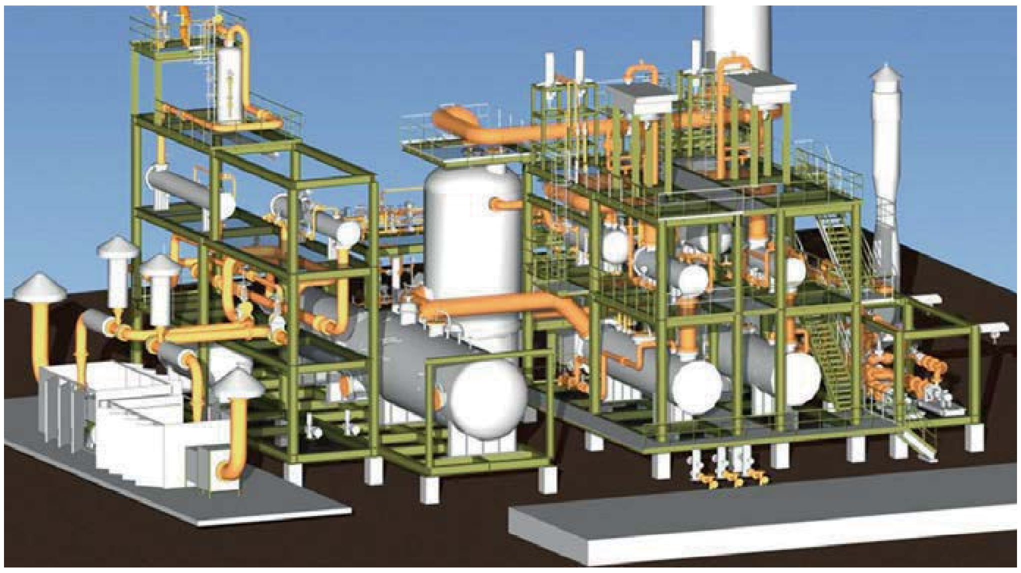


PHOTO: PROSERNAT

Fig. 5: 3D model of the 100 t/d SmartSulf™ unit.

Once the second catalytic reactor is loaded with liquid sulphur, the two automatic 4-way valves are rotated so that the first reactor, originally operated in "hot mode", is switched to operation in sub-dewpoint mode. The second catalytic reactor is switched from sub-dewpoint mode to "hot mode" and is therefore regenerated by vaporising all of the accumulated sulphur, which is then condensed in the external sulphur condenser.

Construction of the SmartSulf™ unit

Both 100 t/d SmartSulf™ units will be delivered modularised as follows:

- 1 module for feed gas pre-treatment (KO drum + air pre-heater);
- 3 modules for the whole catalytic section (including sulphur condenser and 4-way valves);
- 1 package for the thermal section with reaction furnace, burner and waste heat boilers with base plates and access platform supplied separate for site installation;
- 1 incinerator conditioning skid (for tail gas and combustion air);
- 1 separate incinerator and burner.

Fig. 5 shows a 3D model of the 100 t/d SmartSulf™ unit.

Jacobs case study

This case study is about a sulphur recovery project, performed in Europe. The 100 t/d sulphur recovery plant was delivered to the site in seven modules and installed and commissioned at the site in just 28 weeks after the final investment decision (FID). What makes this case study special is the unconventional planning of the project from the earliest phases and how well this plan came together.

Technology selection

After an initial study defining the needs for the new sulphur unit, the request was put out to all reputable companies licensing sulphur technology to come up with their best solution for meeting the sulphur recovery and SO_2 emission requirements in the most economical way, based on total cost of ownership. The installation also needed to be able to cope with possible future more stringent emission regulations at minimum extra cost.

Jacobs Comprimo Sulfur Solutions EUROCLAUS® process (Fig. 6), which complies with European recovery and emission legislation without the need for installing a tail gas treating unit was selected with the option to install a Jacobs Chemetics caustic scrubber, capable of lowering SO_2 emissions to below 50 ppmv, at a future date if environmental legislation becomes more stringent.

Project approach

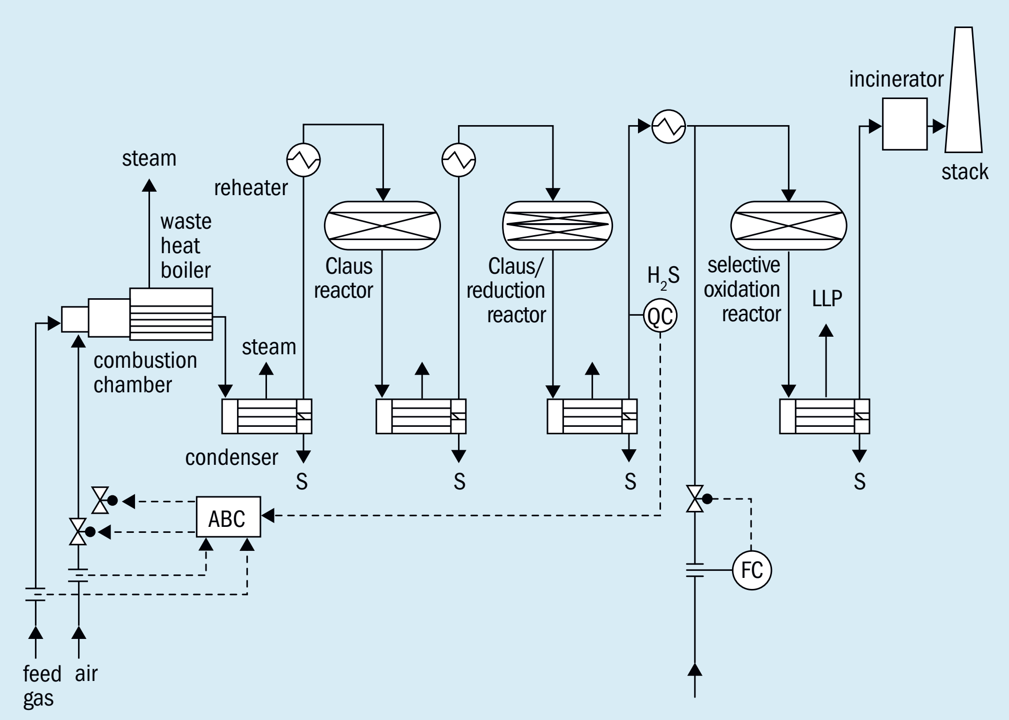
After award of the license and technology package, discussions started on the implementation requirements. During those discussions it became apparent that like most environmental compliance jobs, the available time-window until the compliance deadline was extremely challenging. Decisions on capital investments for compliance-driven jobs is in almost all cases pushed out until it is almost impossible to finish the project in time.

Another requirement was to limit site works as much as possible. Major turnaround activities were planned during the implementation phase making labour availability and cost an issue, in addition to that they wanted to limit the opportunity for their operations and maintenance people to implement "nice to haves".

Immediately, this naturally led to the idea of modular delivery of this unit. After some capital investment comparisons this idea was embraced and already at this very early stage, the decision was made to execute the project in a modular fashion.

The other idea that was put on the table was to engage with Jacobs for the entire engineering, allowing direct transfer of knowledge from licensor to FEED and detailed engineering contractor and enabling minimum FEED activities,

Fig 6: **Jacobs Comprimo Sulfur Solutions EUROCLAUS® process**



Source: Jacobs Comprimo Sulfur Solutions

limited to what is really needed for detailed engineering.

The client however decided to stick to their capital investment process, asking for competitive pricing and a decision gate after the FEED phase. The plan was launched to estimate all phases including a small bridging fund and an early package that allowed the client to go out for competition without losing time. In this approach, the needs and wishes of the procurement department are served, and Jacobs was able to continue the works and plan up to the turn-around activities of the refinery.

This approach led to a total award to Jacobs, combining local strengths, expert knowledge, cost efficiency in Jacobs' high value engineering centre and long term experience in modular delivery. During every step, competitiveness needed to be proven whilst having full focus on schedule driven delivery.

The total award included modular delivery by a remote Jacobs entity and on site contract and construction management by Jacobs' local operations. This approach of integrating the whole chain led to a solution that could meet the schedule that would otherwise have been impossible if all classic project execution steps and tendering periods had been followed.

Together with client resources from the project department, maintenance and operations, the plan was further optimised to satisfy the project needs whilst allowing client governance.

BEP/FEED

To save time and establish a solid basis for this fast track project, Jacobs was allowed to extend the PDP package into an extended BEP and later on into a complete FEED. Getting the basis right was recognised to be of extreme importance since the execution schedule did not leave any room for revisiting design principles. By allowing the expert knowledge to carry on into the FEED phase, a solid basis for subsequent phases was secured and the step to co-ordinate between licensor and FEED contractor including necessary checks and reviews was eliminated. At the end of FEED, specifications for all long lead items were ready to go to the market, already having full licensor approval. In this way, surprises that might have come from a lump sum EP modular vendor were limited even further.

Modular execution

As part of the FEED phase, a tendering package was made to put detailed engineering and modular delivery of the sulphur unit on the market. For civil works and brownfield activities like tie-ins, the local contractor was chosen to secure site-knowledge and for easy co-ordination with maintenance and production. This relatively small portion of the total investment cost was later continued into construction and contract management, supporting the client project team. In this case study, the local contractor was a Jacobs operation that had already been providing services to the site for many years.

For detailed engineering and delivery of the modules (Fig. 7), a remote location, far from the site was chosen. The choice was based on proven delivery capabilities, price and the explicit wish to limit scope changes by implementing nice to haves. The extremely challenging schedule did not allow for disruption caused by such changes.

To allow the client project and PMC team to ensure the right quality was delivered and the right norms and standards were implemented, typical document reviews were agreed at 60% and 90% readiness of the detailed engineering. For inspection of the modular construction, a two week visual inspection by client operations and the maintenance team was implemented at approximately 70% readiness of the modular construction, allowing the whole team to focus on the new plant only. Mandatory inspections by NoBo and other authorities were organised in the modular shop. The two-week inspection by the client team at this remote location was extremely successful. Key improvements for operability and maintainability could be implemented in the shop. This way of organising the review allowed for crucial client input whilst limiting the disruption of the project execution to two weeks, carefully planned up front.

The detailed engineering review, however, ran behind schedule. Carrying out the detailed engineering outside of Europe and therefore lacking knowledge of European and client regulations led to a significant amount of work that had to be redone and an enormous time pressure on the engineering staff to meet the deadlines and allow timely ordering of time-critical project items. During project evaluations, the aspect of ensuring local engineering knowledge during all phases was mentioned as one of the main lessons learned in this project. These resources were brought in after the 60% review and, together with an EP delivery team that was determined to deliver on time, they managed to deliver high quality engineering packages with less than two months delay. The majority of this delay was later on recovered by increasing the modular shop workhours and logistic planning of the shipments to Europe.

OSBL

All planning for the brownfield scope, civil works, permitting and site preparation was done by the local Jacobs team. The fact that the ISBL was also carried out by Jacobs allowed for an integrated approach and optimised schedule. As soon as major parts of the ISBL scope were ready, they could be shared with the OSBL team, reviews on interfaces were done jointly, priorities were synchronised and documents needed for permitting and civil works were shared at the earliest availability. This integrated schedule led to the simultaneous shop fabrication of the modules and site preparation and civil works to enable the modules to be mounted at their final location upon arrival. Whilst the modules were being shipped, concrete was curing at site.

Site construction

The site was located close to a deep sea port, this allowed for module sizes up to 25 m x 10 m x 15 m. Special transportation from the harbour to site took only a few hours from shipping dock to actual location. Because of this proximity, the modules could be stored temporarily at the port and after transportation to site. The modules, ranging from 19 to 127 tonnes in weight, were immediately placed on their final location. Total installation of the modules from ship to final location was done in one week, which helped in part to recover some of the delayed schedule. After the arrival of the containers with loose elements, to be mounted in the modules after installation, site finishing works began. It took just over three months to do all the field welding, mounting of remaining instruments and hooking up of electricals and instrumentation.

The modular scope consisted of seven process modules and two pipe rack modules. The modules contained equipment, piping, valves, and instrumentation. After seven months working on site with 206,000 hours and no lost time incidents the unit was successfully taken into operation.

Testing, commissioning and start-up

The recovery of the engineering as described above, involved the local team that also supported the construction management team. This included some very thorough checks with the local civil and electrical engineering team, leading to a flawless installation of the modules. After the installation and field works to hook-up the modules, extensive testing began at the exact scheduled date. Commissioning and start-up went as per plan, allowing for start-up at the scheduled date, together with start-up of the entire refinery after turnaround.

After completion of the project, the project teams received safety achievement awards from both the client and Jacobs organisation. The teams were also praised for their "one-team approach" and commitment to get the job done.

PHOTO: JACOBS COMPRIMO SULFUR SOLUTIONS

Fig. 7: Module for a 100 t/d sulphur recovery unit.

Lessons learned

As always, project evaluations done after the project is executed always raise items that could have been done better. Some of the main items for improvement as well as the positive lessons that deserve consideration for future projects are listed below:

First steps in feasibility of the project were some three years before mechanical completion. Joint agreement that this was a very tight schedule was crucial to allow strategic thinking and decision making in the early stages.

The client project department had enough influence to convince procurement and contracting that a conventional approach would not lead to the desired outcome. The very strong project sponsor was instrumental in taking this step.

Allowing the licensing team to continue to FEED kept specific sulphur knowledge captured in the delivery team. This led to flawless implementation of design features like very high temperatures, very low allowable pressure drop and sloping of lines, crucial in the design of sulphur plants. In this way rework during detailed engineering and construction was prevented.

Carrying out the detailed engineering and modular construction at a remote location was successful to some extent. The goal of preventing nice to haves was met but for detailed engineering, guidance by local resources to secure adherence to rules, regulations and client standards turned out to be crucial.

Taking the project away from the site allowed client staff to fully focus on the refinery turnaround whilst having specialists taking care of the new sulphur unit.

Modular construction at an overseas location was perceived as too remote. Adherence to European regulations caused extra travel and the need to send certain specific items first from Europe to the modular shop and later shipping them back to Europe as part of the module.

The integrated schedule, allowing for modular production and site works at the same time, was perceived as extremely efficient and key to achieving the schedule.

The approach led to a strong reduction of craftsmen needed at the site. This resulted in better safety and a project executed well within budget.

Projects driven by extreme factors like an "impossible schedule" often lead to an innovative approach. Making a good plan and then making every effort needed to follow the plan certainly paid off for the project in this case study.

KT case study

KT – Kinetics Technology, process engineering contractor, part of Maire Tecnimont, has recently been involved in the development of the licensing, engineering and procurement of the sulphur recovery plant serving the sour gas processing facilities of one of the major gas fields discovered in the Mediterranean Sea.

The project, awarded to KT in May 2016, proved to be one of KT's most inspiring projects due to the technological and organisational challenges that needed to be overcome in order to successfully complete the project.

The process scheme selected for the sulphur plant includes four SRU packages, each with a capacity of about 30 t/d of sulphur. Despite the small capacity, major technological solutions were needed to meet the demanding performance required, due to the "difficult to treat" feedstock and the expected wide ranging scenarios of plant operation. The project execution has been customised to the short timing given for delivery of the plant, introducing a new strategy of overlapping the licensing and engineering phase, considering the full modularisation of the plant, essential for the fulfilment of early plant production.

Design requirements

The SRUs are required to comply with the following main process guarantees and project requirements:

- overall sulphur recovery efficiency of at least 99.9%;
- SO_2 emissions in the stack not higher than 150 mg/Nm³ at 3% O_2 on a dry basis
- sulphur quality;
- full modularisation of the units;
- project execution schedule of 12 months further accelerated at 9 months during EPC phase;
- SRUs start-up within 2017.

The SRU packages have been designed to treat acid gas from the acid gas removal unit (AGRU) and sour gas from the sour water stripping unit (SWSU).

Technical challenges

The main technological issues relate to the capability of the SRUs to treat the very lean acid gas from the AGRU which has a high content of impurities such as mercaptans and BTEX. Extreme flexibility in plant capacity from 100% to 11% was required to support operation in all phases of the project. The feedstock H_2S content, ranging from 4.2% to 15 vol-% of H_2S, together with the low turndown and the presence of impurities required an optimised plant configuration with the implementation of H_2S enrichment and co-firing technologies in order to be able to guarantee smooth operation and performances in all operating cases. Beside the SRE of 99.9%, the fulfilment of SO_2 emission (i.e. 150 mg/Nm³) has been met by including recovery of the H_2S from the liquid sulphur degassing and storage section. In addition, the high level of mercaptans present in the acid gas, confirmed when the project was already started, requires the introduction of a flue gas SO_2 removal system to be installed in a later stage with the SRU package is in operation.

Selected plant configuration

Based on these main constraints, KT has developed an advanced plant process comprising the following sections:

- acid gas enrichment – KT RAR™ multi-purpose process;
- KT modified Claus process;
- KT liquid sulphur degassing process;
- KT KT RAR™ tail gas treatment;
- KT thermal incinerator and WH recovery package.

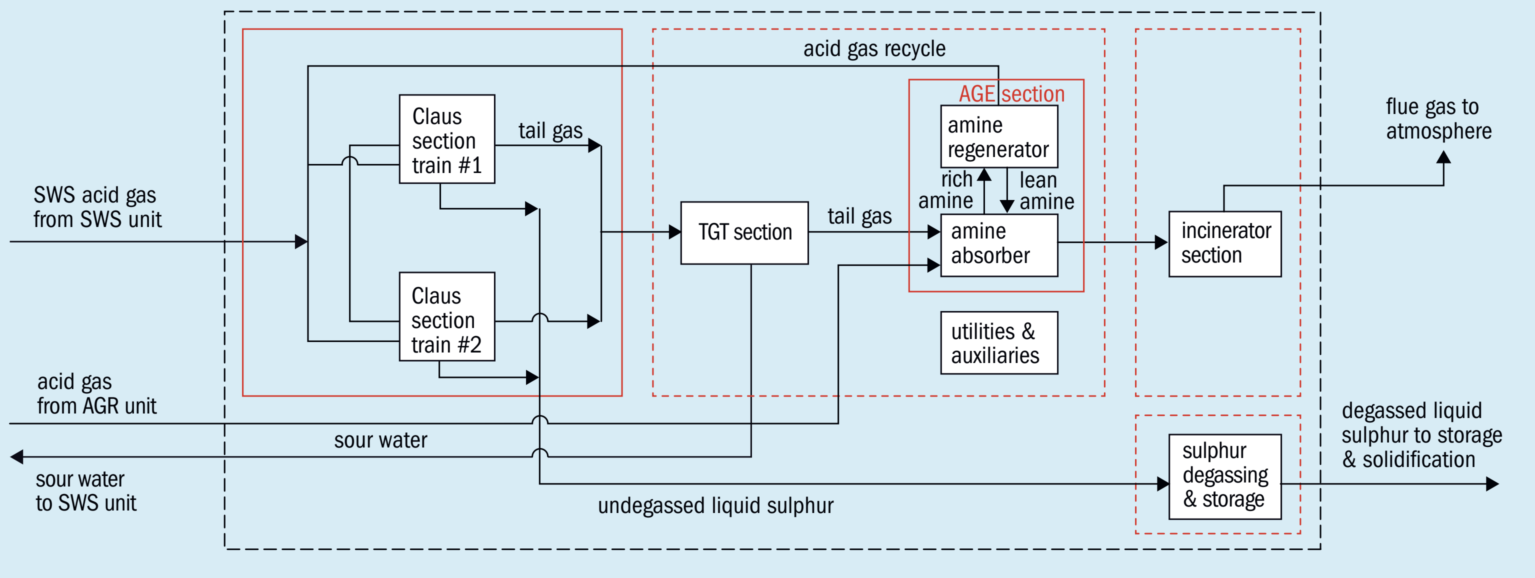
A block diagram of the SRU packages is shown in Fig. 8.

Full modularisation of the plant

From the beginning of the project, the Client has requested that the site construction time be minimised and has scheduled the start up for 2017 to guarantee the early production of the plant. In order to meet this challenge, extensive plant modularisation including structural, piping, instrumentation and equipment has been taken into account from the beginning of the design. Reduction of construction schedule due to the use of a modularised approach must be duly supported by an early engineering phase, early module design and an early procurement phase. Several critical milestones have to be implemented, the most important ones being: increased standardisation of design where applicable, increase of interface co-ordination between all the disciplines involved such as process, engineering and procurement and start-up of the procurement supply chain at a very early stage.

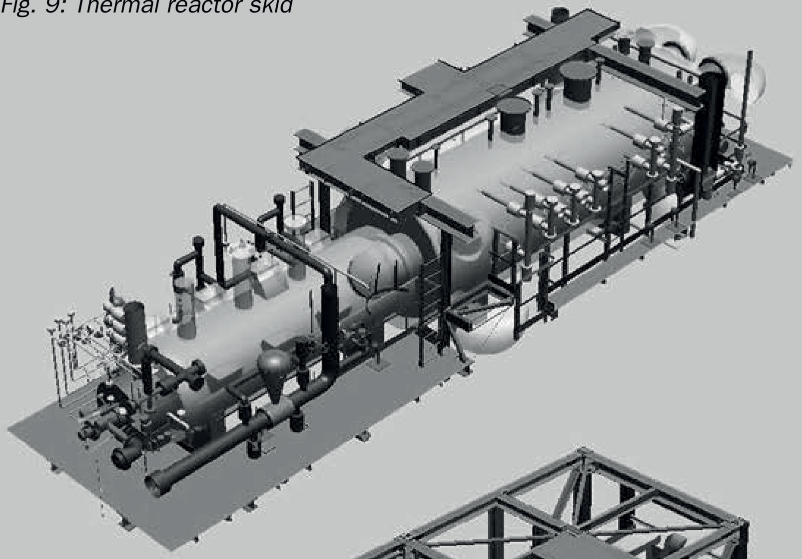
The process design and the detailed engineering has been executed and developed in parallel with the optimisation of

Fig 8: **Plant block flow diagram**



Source: KT – Kinetics Technology

Fig. 9: Thermal reactor skid



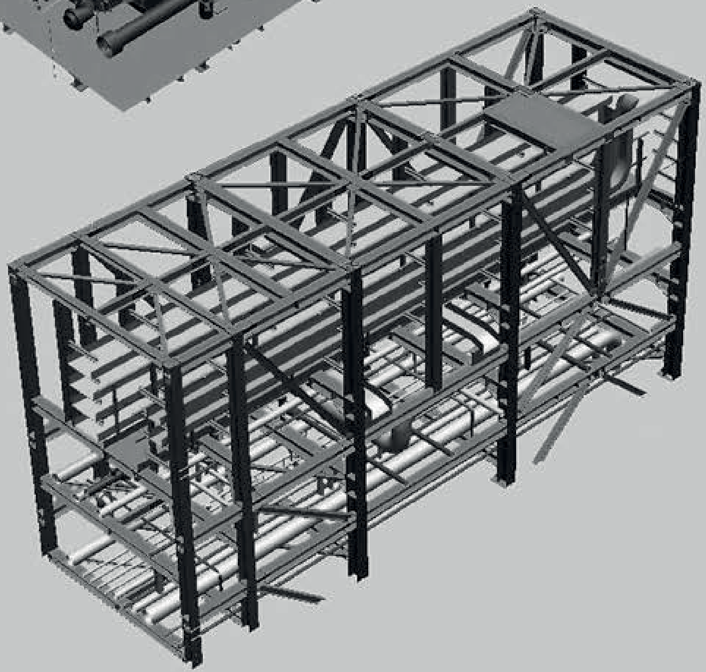


Fig. 10: TGT pipe rack skid

PHOTO: KT – KINETICS TECHNOLOGY

Fig. 11: TGT skid assembly containing hydrogenation reactor, inline heater, TGT waste heat boiler (on the back), filters and compact heat exchangers on the bottom.

full plant modularisation as the main basis of design. From the outset the battery limits for each skid battery have been defined and all items have been divided between "on skid" or "loose". An optimised strategy for the procurement chain has been applied from the beginning. The orders of all the equipment and instruments on skid have been defined and finalised in order to receive equipment and instruments on time to perform the skid construction and shipping on schedule.

As shown in Figs 9-11 modularisation and level of completion of the skid have been maximised in terms of piping and instrumentation in order to minimise site activities.

Most of the skids have been prepared in a dedicated yard located in a harbour in Italy. When completed the erection of the skids have been replicated at the yard as it would be at site for consistency checks and to guarantee the coupling between each skid once at site.

To minimise site activities, before shipping each skid has been mechanically and functionally tested, pre-commissioned and then carefully packed for protection during shipping.

Thanks to extensive co-ordination activities, the sequence of skid preparation and shipping have been aligned to an optimised delivery schedule directly linked with the construction programme in order to have the skids erected at site "just in time". The main objective has been to minimise the movement and storage of the skids in a congested area on site during the construction phase to prevent possible damage. Applying this well-established operation mode that has already been used by KT for other projects, once the skid is delivered to the site it is ready for quick erection and start-up.

In this project KT has had to deal with many technological issues, which have been overcome thanks to the experience, flexibility and problem solving attitude of the engineering team.

When the project was awarded to KT in May 2016 there was no basic design available (the project had to be started from scratch) and there was only very limited sour gas analyses available from the gas field, due to the recent discovery and huge extent of the gas reservoir. Feedstock adjustment was required during project execution.

The success in delivering the fully modularised SRU and AGE units in only nine months demonstrates the great competence that KT has built during 40 years of experience, characterised by the capability to fully adapt to any client's requests, overcoming technical challenges, to achieve project schedules on time, on budget, on quality and in full compliance with client's expectations. ■

Thiopaq-SQ: the SRU for lean acid gases

Biotechnological treatment of sour and acid gases using the Thiopaq technology platform is a proven technology. **J. Klok, G. van Heeringen, R. de Rink** and **J. Wijnbelt** of Paqell introduce Thiopaq-SQ: the next generation of the Thiopaq O&G process for environmentally friendly gas desulphurisation. In comparison with alternative SRUs, the Thiopaq-SQ process realises a major reduction in opex by ensuring optimal activity and selectivity of the catalyst.

The oil and gas industry is facing challenging times as it is confronted with a prolonged price weakness of crude oil and natural gas, combined with a declining number of easily recoverable sweet gas resources. Thus, there is a strong demand for flexible and cost-effective desulphurisation solutions to enable the development of more challenging wells. Cost-effective gas desulphurisation is particularly challenging for projects with small to medium quantities of sulphur. This article provides one of the best approaches to overcome these demanding circumstances.

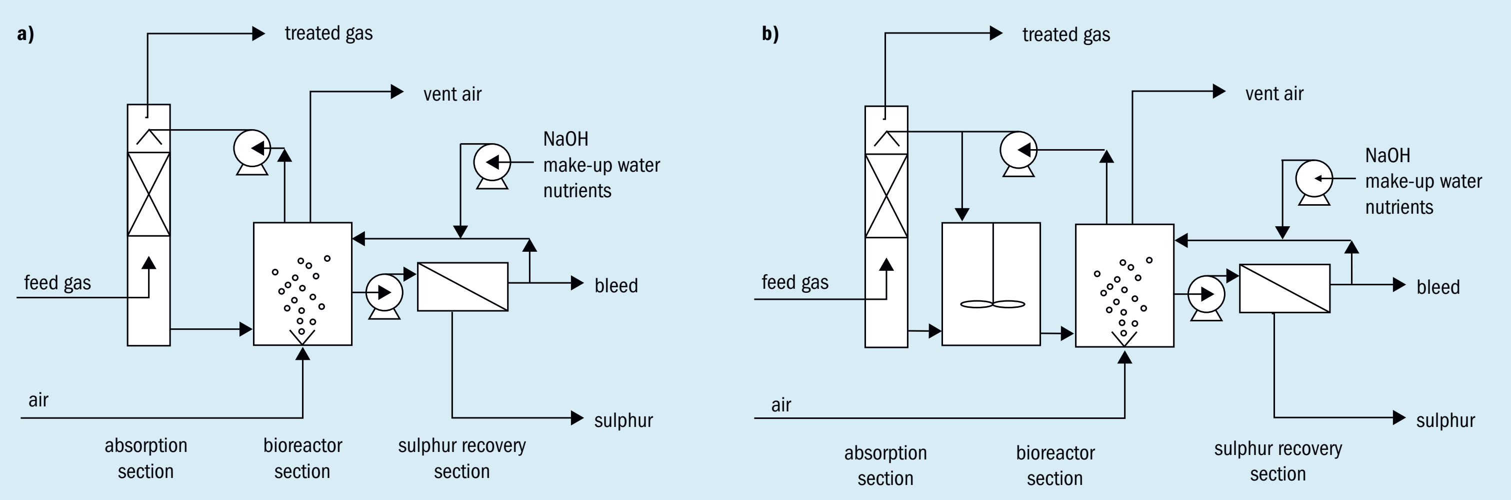
The recovery of small (>0.5 t/d S) and medium (up to 100 t/d) quantities of sulphur from sour gas streams commonly occurs via either a Claus, liquid redox or biotechnological process. Typically, the Claus process operates at high temperatures and is expensive and cumbersome for lean acid gases, i.e. those with relatively low H_2S content. In redox processes the chelating compound is subject to degradation and hence, continuous replenishment of this expensive chemical is required. By contrast, the catalyst used in the biotechnological process (Thiopaq O&G) is continuously replenished by nature cost-free, while low-cost caustic is the main chemical to be added. Therefore, biotechnological desulphurisation is considered environmental friendly.

The Thiopaq process, driven by the biotechnological conversion of bisulphide (HS^-) to elemental sulphur, was initially developed for sweetening H_2S-containing gas streams from anaerobic waste water treatment units[1]. Paques BV commercialised this process in 1991; today, over 240 Thiopaq installations have been built worldwide. The Thiopaq O&G process is tailored for the oil and gas industry, it is proven and competitive and has secured its place in the global market. This article discusses the most recent breakthroughs in the biological desulphurisation process which have resulted in a new technology, Thiopaq-SQ.

Biotechnological desulphurisation technology

The traditional biotechnological desulphurisation process consists of three simple, integrated steps (see Fig. 1a): absorption, regeneration and sulphur recovery. In the first step, feed gas is counter-currently contacted with alkaline solution. H_2S is absorbed and converted to bisulphide, thereby consuming alkalinity of the process solution. The feed gas, ranging from

Fig 1a: **Standard Thiopaq O&G scheme and** 1b: **new Thiopaq-SQ scheme**



The Thiopaq-SQ line-up contains an extra anaerobic bioreactor between the absorber and aerated bioreactor to secure optimal biological selection for highly-selective bacteria.

Source: Paqell

Fig 2: Scanning electron microscope (SEM) picture

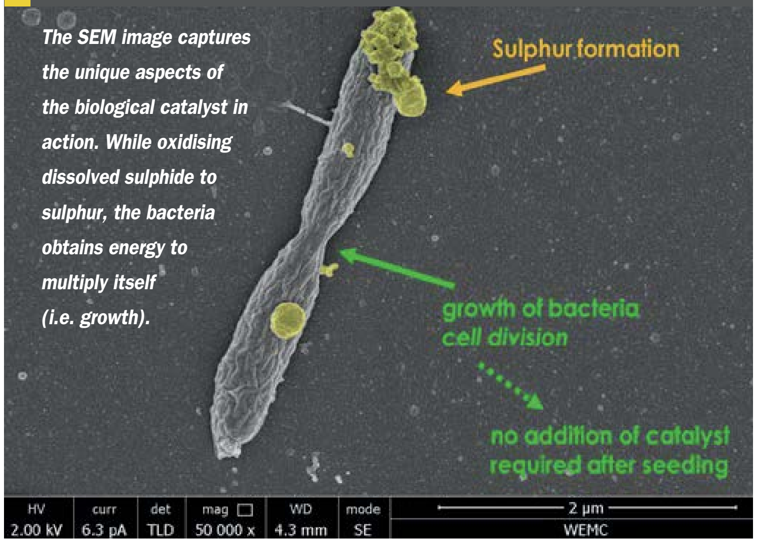
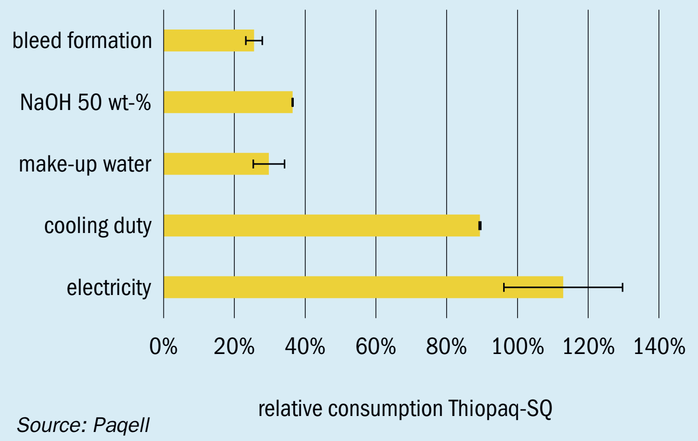


PHOTO: PAQELL

Fig 3: Comparison of the relative consumables of Thiopaq-SQ when compared to Thiopaq O&G



Source: Paqell

atmospheric pressure to a maximum of 80 barg, is not restricted to a minimum or maximum H_2S level. The treated gas is routed through a treated gas knock-out vessel before further processing.

The second step takes place in the bioreactor, in which the bisulphide-rich solution is mixed with air and the bacteria oxidise the dissolved bisulphide to elemental sulphur. In this way, the process solution is regenerated (alkalinity is restored).

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

The biotechnological desulphurisation is characterised by the following[2, 3]:

- Low environmental impact: H_2S removal efficiency > 99.9%
- Lower capex: less equipment i.e. no requirement for burners and reboilers compared to conventional AGRU + Claus + TGTU. Regeneration and sulphur recovery sections operate at atmospheric pressure and ambient temperature
- Simplicity: less operator manning levels. Produced bio-sulphur is hydrophilic and behaves like a relatively stable suspension without clogging
- Safety: no free H_2S downstream of the absorber, ambient temperatures for the whole system, atmospheric pressure in bioreactor and sulphur recovery section
- Produced bio-sulphur is the basis for a range of new agricultural products designed to act as ingredients for liquid fertilizers and liquid fungicides
- Small footprint

Selection of preferred bacteria

A unique aspect of the biological desulphurisation process is its catalyst, a mixture of sulphide-oxidising bacteria. These organisms are naturally occurring, and multiply because of the released energy from the oxidation of sulphide to elemental sulphur. Therefore, after initially seeding the system at start up, no addition of fresh catalyst is required. It should be noted that in comparison to traditional catalyst this is unique since traditional catalyst is subjected to degradation and hence, continuous replenishment of this expensive chemical is required. In Fig. 2, a picture of a scanning electron microscope (SEM) is shown which captures the unique aspects of the biological catalyst. Cellular division ensures that fresh catalyst is made continuously without losing catalyst activity and selectivity.

In biotechnological desulphurisation units, the efficiency of the biological catalyst is an important factor for the operating expenditure (opex). In most operating plants, some sulphate is formed as a by-product because most sulphide-oxidising bacteria prefer to produce sulphate rather than sulphur. This sulphate production leads to acidification of the process solution and caustic addition is required. Furthermore, a bleed stream is needed to remove the sulphate from the system. The microbial community in the bioreactor also includes varieties of sulphide-oxidising bacteria that are not able to oxidise sulphide to sulphate, but they are normally outcompeted by the faster-growing sulphate-forming species. Therefore, some sulphate formation is inevitable in the current generation of biotechnological desulphurisation processes.

In general, process conditions and environment dictate which bacterial species become dominant in an open bioreactor system. An adaption to the process conditions will lead to a change in the microbial community composition, and hence in the governing functionality of the biocatalyst. An 11-month pilot plant trial (July 2015–May 2016) demonstrated that stimulation of the preferred sulphur-selective species (i.e. not capable of forming sulphate) can be achieved through an innovative process line-up[4]. Fig. 1b shows the new line-up, which contains an anaerobic bioreactor, located between the absorber and the aerobic bioreactor. By using this extra reactor, advantage is taken of the activity and selectivity of different bacteria, which substantially improves the biocatalyst's selectivity for sulphur formation (up to 98%), which in turn leads to strongly reduced caustic consumption rates and a smaller bleed stream. The new line up is named Thiopaq-SQ.

The overall consumptions of Thiopaq-SQ has been evaluated in a recent study[5] as shown in Fig. 3. Significant reductions in the consumption of caustic and make-up water and of the formation of bleed water are obtained: 63, 75 and 74% respectively. In addition, some 10% less cooling is required. Electricity costs are case specific; the addition of an extra pump (see Fig. 1b), which recycles process solution between the aerobic reactor and the anaerobic

Table 1: **Design bases for comparative study** [2, 5]

Design case	Acid gas (lean/rich)	H_2S (mol-%)	CO_2 (mol-%)	S-load (t/d)	Alternative SRU
A	lean gas	2.2	92.0	15	redox-based
B	lean gas	2.9	92.3	70	AGEU + SRU + SCOT
B	rich gas	79.5	15.8	27	SRU + SCOT

reactor leads to a marginal increase of electric consumption only, as it is all at very low pressure.

Bacterial activity

Another vital parameter in the design and operation of any biotechnological process is the activity of biological organisms; in a desulphurisation process, this is the maximum sulphide conversion rate of sulphide-oxidising bacteria. The greater the conversion capacity, the smaller the bioreactor. As this is the largest piece of equipment in a Thiopaq O&G plant, increasing the conversion capacity significantly decreases costs and plot space requirements, and allows higher sulphur throughputs.

After small-scale laboratory tests indicated a much higher maximum sulphide conversion capacity, a dedicated demonstration plant was constructed to confirm this in a full-scale setup. This plant treated off-gas from the SCOT hydrogenation reactor prior to its processing in the SCOT amine absorber with a maximum feed gas flow of 1,200 Nm³/h. H_2S and CO_2 levels in the feed gas ranged from 0.5 to 1.0 mol-% and 10 to 14 mol-%, respectively. This demonstration plant was designed to produce 150 to 250 kg S/day. During operation, conversions as high as 270 kg S/day were obtained.

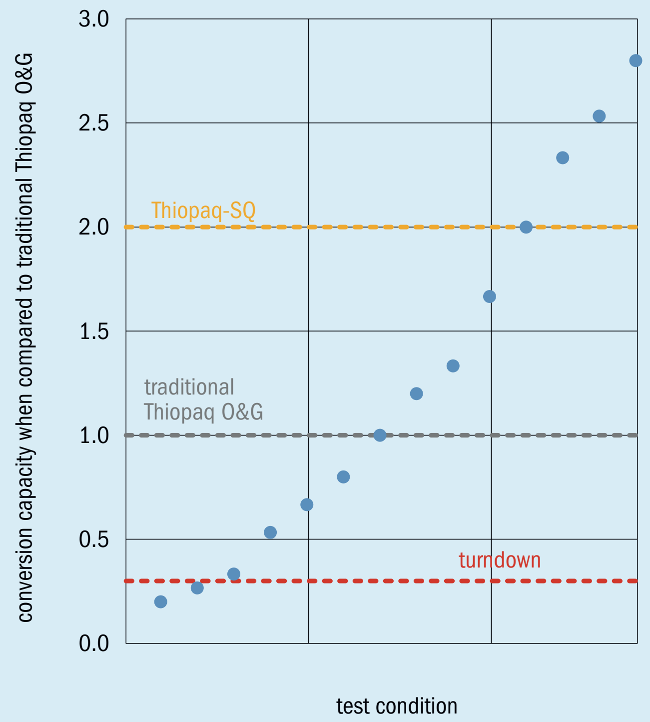
The results of operation for more than a year (May 2014–June 2015) are shown in Fig. 4. Initially, the plant was operated under stable conditions below turndown. Subsequently, the sulphur load was increased stepwise over time, and every step represented a new test condition. The obtained results showed that it was possible to almost triple the volumetric conversion capacity of the bioreactor, relative to the existing Thiopaq O&G technology and new designs were made with double the biological conversion as a standard. In addition, the aerated bioreactor in the Thiopaq-SQ technology can also be designed with this increased biological activity as compared to traditional Thiopaq O&G. This means that the required bioreactor volume is halved for new designs, larger sulphur loads can be handled economically, the turndown of the bioreactor is doubled and the process has a higher tolerance towards disturbances.

Case study

In 2013, a study compared traditional Thiopaq O&G technology to alternative SRU line-ups for amine acid gas treatment, based on an evaluation by an

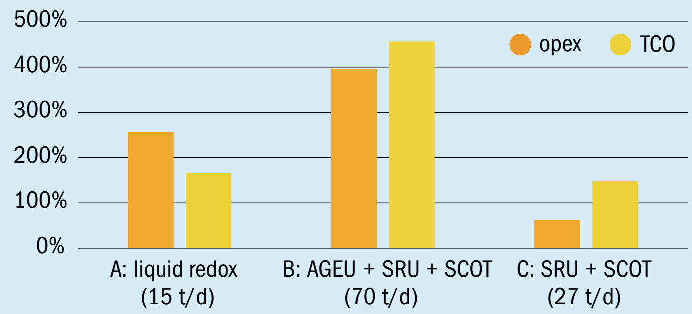
Fig 4: **Demonstration plant test results**

Every step represents a new test condition and sulphide conversion capacity (blue dots).



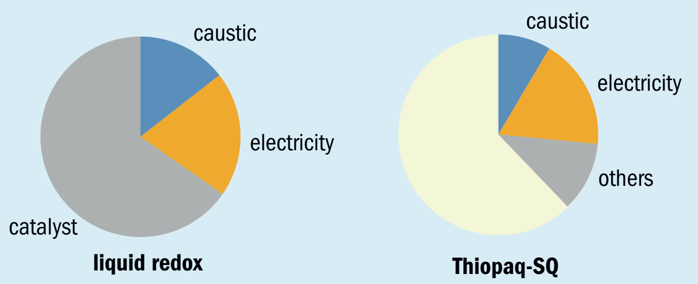
Source: Paqell

Fig 5a: **Comparison between Thiopaq-SQ and alternative SRU for several cases for opex and TCO**[5]



Source: Paqell

Fig 5b: **The comparison between consumables in a typical liquid redox process and Thiopaq-SQ process**



Source: Paqell

independent third party[2]. In this study, several alternative SRU technologies were compared (see Table 1) for both, lean acid gas (case A and B) and rich acid gas (case C). The technologies considered were:

- Case A: Liquid redox based; lean acid gas, 15 t/d sulphur
- Case B: AGEU (acid gas enrichment unit) + SRU (sulphur removal unit, Claus) + SCOT; lean acid gas, 70 t/d sulphur
- Case C: SRU + SCOT; rich acid gas; 27 t/d sulphur

The underlying data of this study has been used and compared with the new line-up of Thiopaq-SQ[5]. The results for both, opex and total cost of ownership (TCO, 15 years of operation with 10% discount rate, taxes excluded) are shown in Fig. 5a.

For the lean acid gas in case A, the differences in opex between Thiopaq-SQ and a redox-based process are mainly explained through the costs of chemicals and catalyst. The bacteria in the biotechnological desulphurisation process are supplied at start-up only, whereas redox-based processes require addition of fresh catalyst on a regular basis. This results in a large difference in opex and consequently in TCO. Fig. 5b shows the comparison between consumables between a typical liquid redox process[6] and the Thiopaq-SQ process based on Thiopaq O&G full-scale plant data and pilot plant Thiopaq-SQ data.

For the lean-gas in case B, the opex of the AGEU + SRU + SCOT units are relatively high due to the enrichment step. The lower the H_2S content in the feed gas, the more that is asked from the enrichment step, resulting in increasing opex and subsequent TCO, making Thiopaq-SQ more favourable.

Application of Thiopaq-SQ for rich acid gas (Case C) is relatively high in opex. However, the TCO is still favourable for Thiopaq-SQ due to relatively high capex and process complexity of the SRU + SCOT processing scheme. Therefore, for rich acid gas cases, the economic assessment depends on project specifics and should be reviewed with life cycle considerations for the entire plant including outside battery limits utilities. ■

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Lean sour gas treatment in China

New processes for the treatment of lean sour gas from coal gasification plants have been developed by Keyon Process in China. The DSR process is a regenerative SO_2 removal process and the ECOSA process is a wet gas sulphuric acid process. The DSR process is capable of removing SO_2 to ultra-low levels for environmental compliance and can be combined with the ECOSA process to produce sulphuric acid or the Claus process to produce sulphur. The DSR unit can also be used as a tail gas treating unit downstream of a Claus unit.

China is a vast country that has insufficient oil and gas resources to meet the country's energy requirements, but is rich in coal reserves. In the 1970s, the Chinese government built 13 syngas plants based on the reforming of natural gas and the gasification of residual oil to improve its underdeveloped industrial and agricultural situation. The syngas produced was used to make fertilizers.

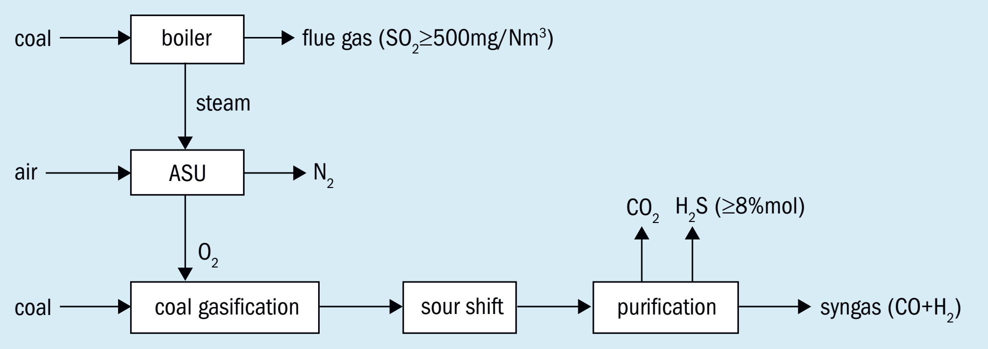
Since 1990, due to increasing domestic agricultural requirements and the increase in energy prices, especially the price of oil and natural gas, the fertilizer plants which used oil and gas as feedstock could no longer meet market requirements and consequently have lost their competitiveness. China therefore started to develop its chemical industry based on coal gasification as feedstock. To date, over 200 pressurised gasification units have been constructed and put into operation, meanwhile the 13 syngas plants, based on oil and gas as raw material, have been suspended and demolished.

Coal gasification and sour gas

Fig. 1 is a block flow diagram of the coal gasification process.

In a coal gasification plant the sour gas comes from two main sources: the majority comes from the coal-fired flue gas, which contains mainly SO_2, and the rest comes from the purification unit which contains H_2S. Depending upon the type of coal, the SO_2 concentration in the flue gas typically fluctuates in the range 500~12,000 mg/Nm³, while the H_2S concentration in the sour gas is in the range 5~35 mol-%.

Fig 1: Block flow diagram of the coal gasification process



Source: Keyon

Coal-fired flue gas

Coal gasification requires substantial steam input, leading to big capacity boilers and large gas output. For example, a 600,000 t/a coal-based methanol plant, requires three boilers, each with 320 t/h (220 MW) evaporation capacity, which produces about 1,500,000 Nm³/h flue gas in total.

Coal-fired flue gas has a low but widely fluctuating SO_2 concentration. The SO_2 concentration in the flue gas depends on the sulphur concentration in the coal. In general, due to combustion and downstream equipment corrosion requirements, the boiler can accept a sulphur concentration of 0.2~8 wt-% in coal giving a corresponding SO_2 concentration in the flue gas of 500~12,000 mg/Nm³.

Coal-fired flue gas also contains a large amount of impurities, dust, heavy metals, NOx, Cl^- and F^-.

Sour gas from purification units

Sour gas from purification units has a low and variable H_2S concentration. The concentration of H_2S can fluctuate in the range of 8~35 mol-%, depending upon the sulphur content of the coal and the type of purification process used. For example, when the sulphur content of coal is 0.8 wt-%, using the semi-lean Rectisol process, the H_2S content of the sour gas is generally 20~24 mol-%; if the sulphur content is lower than 0.5 wt-%, the H_2S content will be lower than 20 mol-%, i.e. 15~18 mol-%.

Usually the design sulphur concentration of coal is quite different to the actual coal type in operation, leading to a sour gas flow rate that fluctuates, making it difficult to achieve stable plant operation. When switching coal, the H_2S concentration and flow rate will change simultaneously; this will also make it difficult to achieve normal stable operation of the plant.

Sour gas treatment

The sour gas treatment approach, irrespective of whether it is coal-fired flue gas or purified sour gas, is to convert the sulphur compounds into sulphur or sulphuric acid, thereby reducing the sulphide content and meeting SO_2 emission standards.

Flue gas treatment

Since the coal-fired flue gas flow rate is normally huge and with a low SO_2 concentration, scrubbing is the most widely used treatment. Different scrubbing processes are summarised in Table 1.

Ammonia scrubbing is the most common process used with 80% of units using this process for coal gasification boilers. It also produces a useful byproduct $(NH_4)_2SO_4$, however, due to the high price of ammonia and ammonia slip problem in the emission, it is currently being used less and less, especially in the case of large capacity plants. Wet scrubbing with hydrated lime (Ca scrubbing) has been used to control emissions for many years, but the process consumes large volumes of water and produces a byproduct that is difficult to handle. By contrast the Cansolv process is technically attractive but is not widely used in gasification projects.

Keyon Process offers an alternative flue gas treatment, the DSR process, which is capable of removing SO_2 to ultra-low levels (as per Chinese government requirements), i.e. $SO_2 \leq 50$ mg/Nm³ (O_2 @ 3 mol-%). The recovered SO_2 is sent to a Keyon patented ECOSA unit to produce sulphuric acid.

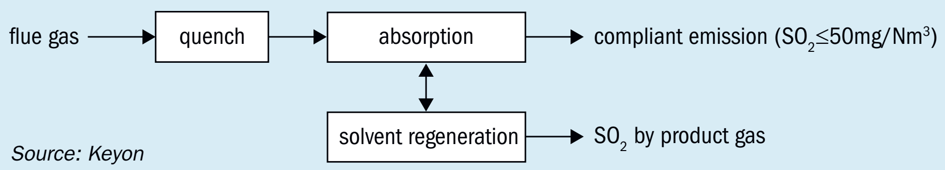
Table 1: Widely used scrubbing processes

	Absorbent	Byproduct	Market share
Ammonia scrubbing	$NH_3 \cdot H_2O$	$(NH_4)_2SO_4$	primary
Ca scrubbing	$Ca(OH)_2$	$CaSO_4$	less
Na scrubbing	NaOH	Na_2SO_4	less
Cansolv	n.a.	SO_2	n.a.

Fig 2: DSR process data

$$R_1^+R_2^- + SO_2 + H_2O \underset{\text{regeneration}}{\overset{\text{absorption}}{\rightleftharpoons}} R_1^+R_2^- + H^+ + HSO_3^- \underset{\text{regeneration}}{\overset{\text{absorption}}{\rightleftharpoons}} R_1HSO_3 + HR_2$$

Process flow



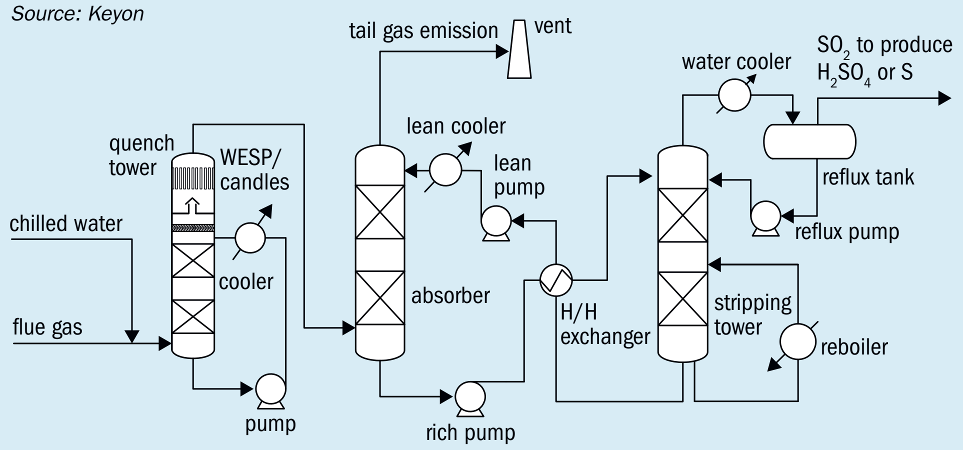
Source: Keyon

Table 2: Data from a DSR unit of a coal-fired boiler

	Flue gas flowrate	temperature °C	SO_2 concentration	Byproduct SO_2 concentration
Original	500,000 m³/h	130°C	2,500 mg/Nm³	-
After treatment	-	45°C	≤50 mg/Nm³	≥90 mol-%

Fig 3: DSR process

Source: Keyon



DSR process

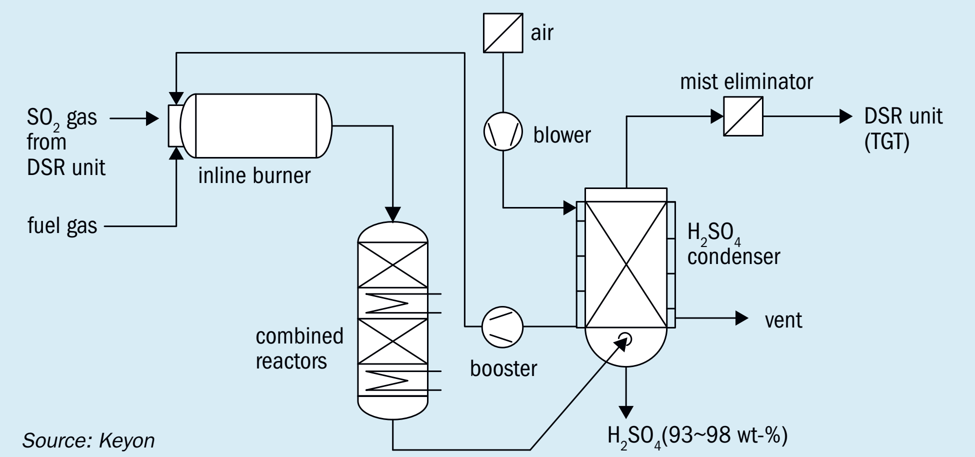
DSR is short for desulphurisation and sulphur recovery. The DSR process is based on a unique organic solvent, developed by Keyon Process, which has excellent absorption and selectivity for SO_2 (with almost no absorption of CO_2, N_2 and O_2). When the solvent is contacted with the flue gas, SO_2 will be absorbed, depleting the flue gas of SO_2 to meet strict emission standards. The rich solution containing absorbed SO_2 is sent to the regeneration tower, and heated to 115~125°C, to release the SO_2 from the rich solvent. The regenerated lean absorbent is then returned to the absorption tower. This forms an absorption/regeneration recycle loop. The released SO_2 can be sent to the acid plant to produce sulphuric acid or sent to a Claus unit to produce sulphur.

At the heart of this process is the DSR solvent, which consists of an organic base (R1OH) and an organic acid (HR2). $R1^+R2^-$ is formed via a neutralisation reaction. The principal reactions for SO_2 absorption are shown in Fig. 2.

From the data in Table 2 it can be seen that the DSR process is suitable for treating flue gas with large flow rates and low SO_2 concentrations. The scrubbed gas guarantees clean emissions, and the absorbent can be used repeatedly. No feedstock e.g. ammonia or calcium oxide is required.

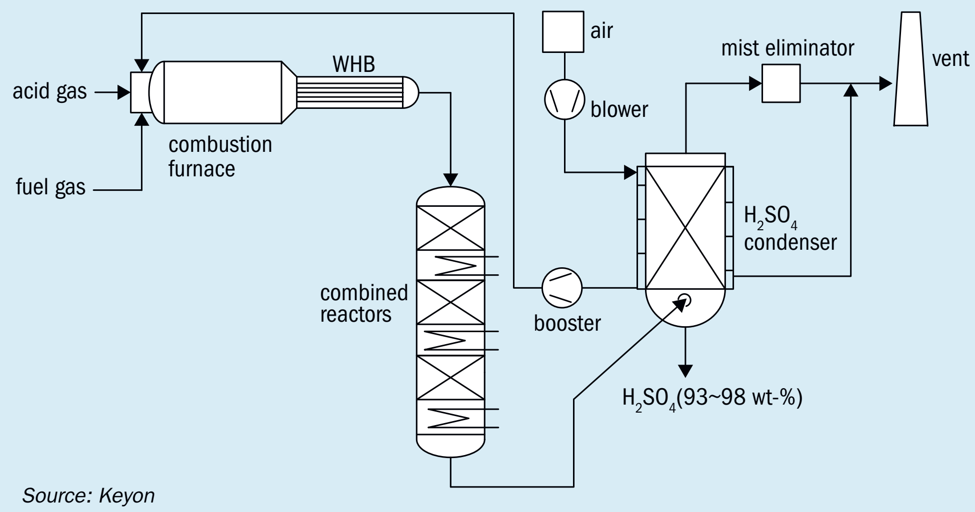
Fig. 3 shows a process flow diagram for the DSR process.

Fig 4: **ECOSA + DSR process**



Source: Keyon

Fig 5: **ECOSA process**



Source: Keyon

DSR + ECOSA

The recovered SO_2 from the DSR process can be used to produce sulphuric acid by the Keyon ECOSA process. A typical process flow diagram is shown in Fig. 4

The concentration of recovered SO_2 from the DSR process normally is higher than 90 mol-%, the other part is mainly water. The output pressure can be controlled higher than 40 kPag to meet the systematic pressure drop of the ECOSA unit and there is no need to compress the gas. In the flowsheet, the SO_2 stream is mixed with hot air (200°C) from the condenser of the ECOSA unit. The amount of hot air will depend on the SO_2 concentration after mixing and is normally controlled within 6~7 mol-% The process gas is then co-fired with fuel gas to increase the temperature to 415~430°C, the inlet temperature of the catalyst bed, to convert SO_2 into SO_3. After conversion, SO_3 reacts with water vapour to form gaseous H_2SO_4, along with a temperature decrease. When the temperature falls below the dew point, the gaseous H_2SO_4 is condensed to liquid H_2SO_4. This all takes place in the ECOSA condenser, a glass tube heat exchange with a special internal design.

Since the off-gas from the ECOSA unit still has a high SO_2 concentration which cannot be exhausted to the atmosphere, the off-gas can be sent to the DSR unit, which then acts as a TGT unit for the ECOSA unit. The off-gas from the ECOSA unit is sent to the quench tower of the DSR unit to cool the temperature to 40-50°C, mixed with feedstock gas and then sent to the absorption tower. After absorption, the off-gas will meet environmental emissions standards. The reaction heat from the ECOSA unit is recovered to produce steam to supplement the steam consumption of the DSR unit. In 2017, Keyon has designed two DSR+ECOSA plants, to recover SO_2 and produce H_2SO_4 for coal-fired boiler flue gas and for smelting off-gas cleaning respectively.

DSR+ Claus

H_2S from the purification unit of a coal gasification plant and SO_2 from the DSR process can react directly to produce sulphur, according to the Claus reaction. This is another way to treat byproduct SO_2 from the DSR unit. However, the H_2S/SO_2 ratio for the Claus reaction is 2:1, but in practice the H_2S/SO_2 ratio varies uncontrollably during plant operation. If the ratio is too high, the excess H_2S in the off-gas from the Claus unit can be burned to SO_2 in the tail gas incinerator and the off-gas sent back to the DSR unit, which could balance the ratio for the Claus reaction; if there is excess SO_2, the SO_2 can be pressurised and sent to a FEED section like a sour shift unit to be converted to H_2S via hydrogenation. After the purification unit the H_2S can be separated and sent to the Claus unit to balance the ratio. Similarly, after DSR purification, the off-gas from the Claus unit can be emitted to the atmosphere.

H_2S sour gas treatment for gasification plant

In a gasification plant, the sour gas containing H_2S generally comes from the purification unit e.g. the Rectisol unit. As the H_2S concentration in the sour gas is fairly low (15-25 mol-%), when the sour gas is treated by the Claus process to produce sulphur, the concentration and flow rate fluctuations make it difficult to achieve stable operation in the Claus plant. In order to guarantee stable hot reaction, i.e. stable combustion, several measures are always taken, such as combustion with pure oxygen, split-flow combustion of fuel gas, split flow of sour gas, and so on. However, in practice Claus units in gasification plants have experienced many problems. In recent years, the wet process for H_2S conversion to sulphuric acid has been widely used in gasification plants in China as a substitute for the Claus process. It shows great advantages such as a simple process flow, high sulphur recovery, off-gas emissions that meet environmental regulations and great operational flexibility to cope with feedstock fluctuations. To date, Keyon Process has licensed 15 ECOSA units in gasification plants according to the flow diagram in Fig. 5.

Fig 6: S-Plus process

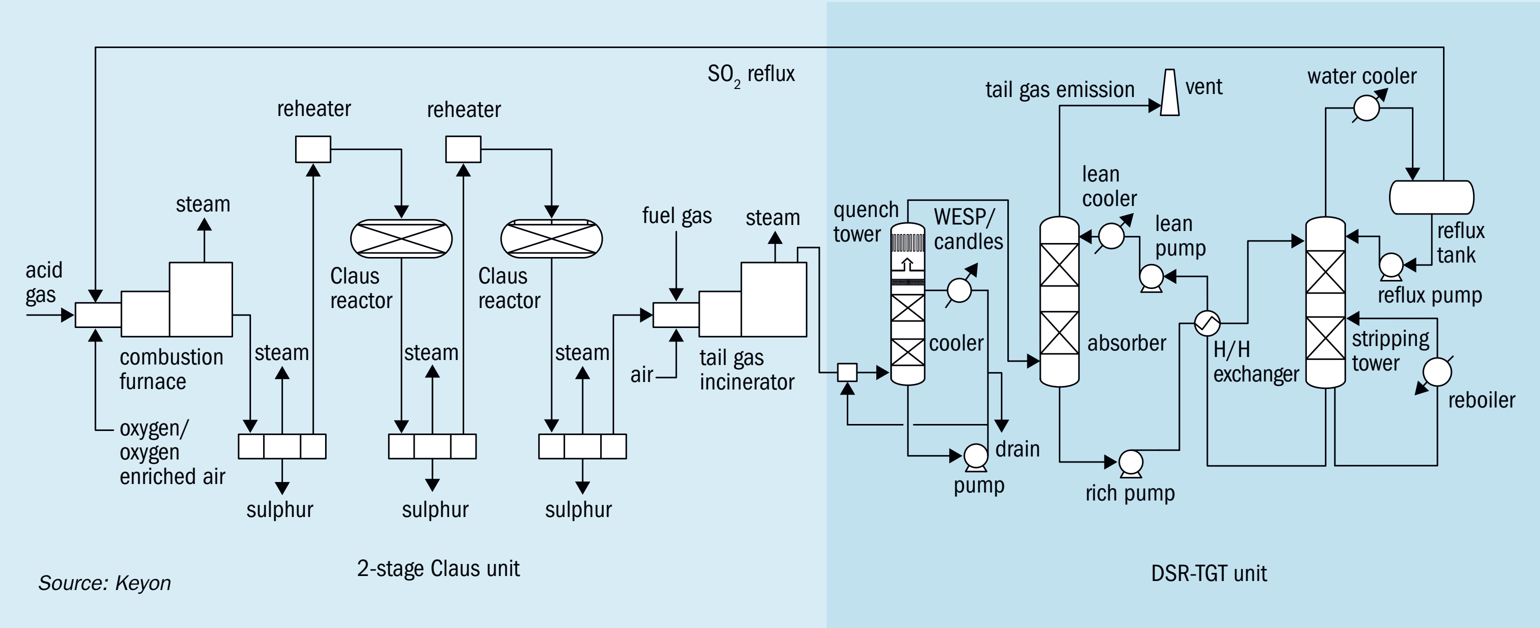
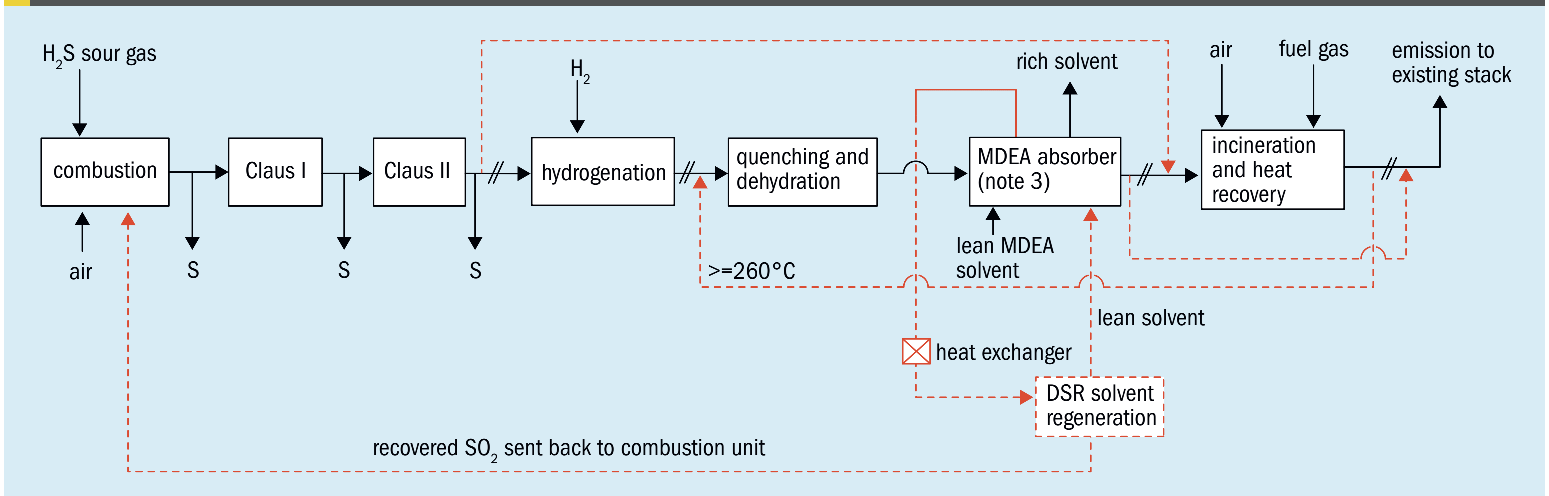


Fig 7: Claus unit revamp



Notes

1. *// represents the isolation.*
2. *red line represents supplemented flow.*
3. *MDEA absorber is to be revamped as DSR absorber.*
4. *In previous process, MDEA solvent was regenerated together in the whole plant.*

Source: Keyon

S-Plus process used for Claus unit revamps

Stringent SO_2 emissions limits, currently less than 100 mg/Nm³ (O_2 @ 3 mol-%) for Claus units, require existing Claus units to be revamped in stages to meet the new standards by 2020. The DSR process can be used for Claus tail gas treatment, providing strong technical support for revamping projects. The combination of the DSR process and the Claus process is called S-Plus by Keyon Process (see process flow diagram in Fig. 6).

In the S-Plus process, sulphur is condensed and separated from the tail gas of the second Claus catalytic reactor at a temperature of 165°C. The tail gas is then sent directly to the incinerator. Co-firing with fuel gas is used to keep the incinerator at a temperature of around 800°C. All sulphur species are converted to SO_2. The SO_2 concentration from the incinerator is in the range of 0.5%-2.5 mol-% (O_2 @ 6%). The downstream boiler recovers heat and produces steam, and cools the gas temperature to ~260°C before it is sent to the quench tower.

The off-gas is quenched to 120°C by pipe spray, before entering the quench tower for wash cooling. The pipe spray is constructed of PEFE liner material and SiC material for the sparger to prevent corrosion. The quench tower has an FRP liner and ceramic packing. The off-gas exits the quench tower at a temperature no higher than 60°C.

To date, Keyon has finished a demonstration project revamping a 15,000 t/a Claus unit, which previously used the SCOT process. Before the revamp, the SO_2 concentration in the off-gas was around 300 mg/Nm³ (O_2 @ 12 mol-%). After revamping, the SO_2 concentration in the off-gas is less than 50 mg/Nm³ (O_2 @ 9 mol-%). In this design, the original hydrogenation process has been abandoned. Gas from the sulphur cooler after the second catalytic Claus reactor is sent directly to the incinerator and then to the quenching and dehydration phase. The original quench tower and MDEA unit has also been abandoned (see Fig. 7).

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 57 58 59 60

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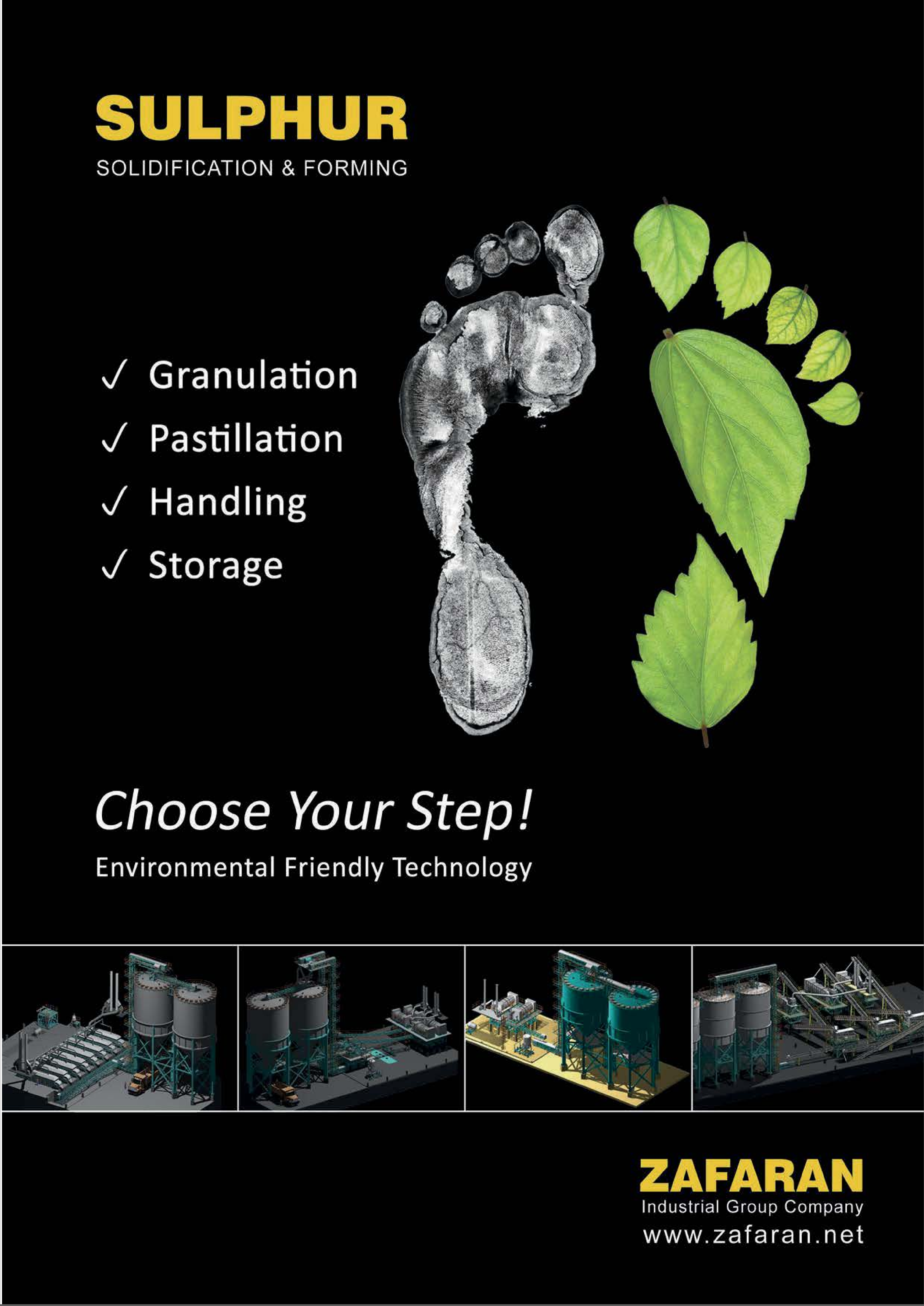
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