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

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Number 387 March | April 2020

SULPHUR

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Kuwait's sulphur boost

Sulphur in North America

Redox reborn

Better control in Claus plants

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ISSUE 387
MARCH-APRIL 2020

BCInsight

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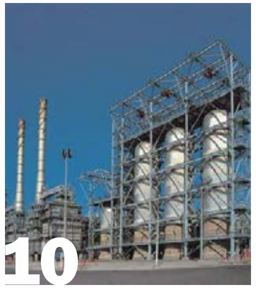
Cover: *A Valkyrie plant under construction, p46.*
Image: Streamline Innovations.



Kuwait's new sulphur

Output to rise significantly due to gas and refining expansions.

Ammonia processing

Applications of SCO units in refineries and petrochemical plants.

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NUMBER 387 MARCH | APRIL 2020

CONTENTS

REGULARS

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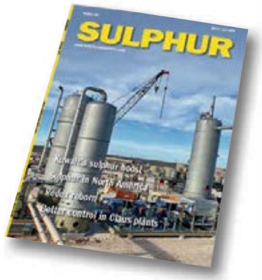
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

Uncharted territory



This year appears to be determined to illustrate the limitations of forecasting. Projecting trend lines into the future, looking at expected completion dates for major projects and global economic projections are all worthwhile activities, and can provide valuable insights for business people, but any prediction is apt to be derailed by what one of our prime ministers supposedly once described airily as; "events, dear boy, events."

On the phosphate side of the business, the sulphuric acid industry is intimately connected with agriculture via demand for fertilizers, which is always dependent upon the vagaries of weather, and hence suppliers are used to a degree of variability and volatility. However, the events of 2020 look to be quite seismic ones for all industries and their effects are far harder to predict.

> "Russia and Saudi Arabia have chosen this moment to have a price war..."

This year's main 'black swan' – long predicted in principle but completely unexpected as to timing – is of course the outbreak of the Covid-19 virus, beginning in China's Hubei province, but at time of writing now spread to all of the continents of the world, and especially virulent in South Korea, Italy and Iran. While China's draconian quarantine measures seem to have contained the outbreak there for now, the effects of the pandemic are still working themselves out across the world, and predictions range from the mild to the apocalyptic. What is more certain is the chilling effect on the world economy, with the airline and wider travel industries virtually shutting down. Quarantining entire nations, as Italy announced yesterday, are of course vital and life saving measures, but will nevertheless have huge consequences in terms of the associated disruption.

At the same time, Russia and Saudi Arabia have chosen this moment to have a price war in the oil industry. Russia, though not formally part of OPEC, had long cooperated on oil production, but decided in early March to break ranks. The impetus was, perhaps inevitably, Covid-19, or in this case the reduction in global oil demand caused by lockdowns, shuttered factories and cancelled flights – China's oil imports dropped by 20% in February alone. OPEC had suggested a 1 million bbl/d production cut, with Russia bearing half of that. Russia balked, and Saudi Arabia has opened up the taps as a countermeasure. Both countries appear to be secretly hoping that the real casualty will be the US tight/shale oil industry, heavily indebted and not able to bear a long period of low oil prices. WTI prices fell to $28/bbl this week – lower than during the 2008 price crash, and reaching levels not seen since 2004. But given both Russia's and especially Saudi Arabia's dependence on oil revenues, they will also feel the pain of a prolonged period of low prices. A revival in the Chinese economy could still turn this around, but there are some long lean months ahead. The worsening economic gloom has in turn triggered a stock market sell-off that has already been called 'Black Monday'. Bond yields have gone negative and the prospect of a global recession is looming. How much of this is merely short term panic remains to be seen.

For the sulphur industry, smaller refinery runs means less supply, but the question will be how the demand side holds up, and that means industry and agriculture. On the acid side of the equation, Chinese lead, zinc and copper mines have reduced output, but smelters have continued operating, and quickly run out of acid storage capacity, forcing shutdowns among smelters as well and sending acid prices into negative territory. The main demand centre – China's Hubei province, which produces 30% of the country's phosphate fertilizer – has been the worst affected by Covid-19. If China has got a grip on the epidemic, and this is a temporary blip, the spring fertilizer application season may rescue the situation, but that remains highly uncertain. In the interim, major consumers like India have been forced to look further afield, to Saudi Arabia, Morocco and the US.

The remainder of the year appears to be shrouded in far greater uncertainty than anyone might have expected just a few short weeks ago. Everyone must now consider any number of factors that they may not have previously given much thought to. Perhaps the only advice under such circumstances are the words of president Dwight D. Eisenhower: that "plans are worthless, but planning is essential."

Richard Hands, Editor

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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

Price Trends

MARKET INSIGHT

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

SULPHUR

In the first two months of 2020 prices held flat-to-firm, much to the contrary of global market expectation. At the end of last year, the market was in almost total agreement that prices would be flat to soft for at least the first 3-4 months of 2020 on the back of poor demand from the phosphates sector, with key consumers reducing operating rates. But that just hasn't happened, with a perfect storm of tight spot availability, easing freight rates and continuous pockets of demand providing support to f.o.b. prices in particular.

In the Middle East, supply-side maintenance and bottleneck issues limiting loading at the UAE port of Ruwais together with continued growth in demand for product to be delivered on a quarterly contract basis have curbed availability in the region, and these factors have provided the foundation for Middle East f.o.b. price support. But prices in the Middle East have also found support from softening freight rates on key routes as there has been wider bulk vessel availability because of ship owners being disinterested in sending their vessels to China because of quarantine rules. Also, when it comes to Arab Gulf producers, it is worth noting that monthly lifting prices for February were all announced at an increase on January levels, noting the first month-on-month increase in 21 months. And it is also worth remarking that Iran's f.o.b. price increased in late-February to $32-42/t f.o.b., the first upwards movement in Iranian fob prices in a year. The price managed to find support because of limited supply for Arab Gulf loading cargoes and a pickup in demand from China, the biggest export market for Iranian product.

The Chinese market has done nothing but surprise so far this year. As was anticipated, with the Lunar New year holidays taking place at the end of January, buyers exited the market in the middle of the month as internal logistics moved away from commodity transportation to people transportation, port inventories maintained healthy levels of 2.7 million tonnes, and consuming plants started to wind down operations. Traditionally, buyers would return to the market 2-3 weeks after the end of the holiday, and during this 4-5 week absence prices would usually hold flat-to-soft, but not this year, as holidays were extended across the country with the outbreak of the coronavirus and the implementation of measures to curb the virus spreading. End-user buying on a c.fr basis remained largely absent until mid-February with fertilizer plants either closed or operating at very low rates and port inventories climbing to 3.1 million tonnes, the highest ever recorded level. Yet, despite this lack of end-user enthusiasm, prices for granular product on a domestic ex-works and c.fr basis have increased. Ex-works prices started increasing in mid-February and had gained Yn 80/t on a mid-point basis by the end of the month, to achieve the highest price since September. And when it comes to the import market, granular prices started rising in the last 10 days of the month to move over the mid-$60s/t c.fr for the first time since November. The price increase has been attributed to port inventories, though being largely being in trader hands along with minimal new deliveries because of a tight supply side and a reluctance from vessel owners to deliver product to the country, in partnership with slowly improving end-user demand causing concern that port inventories are finite and will not easily be replenished in the near term.

But it's not just been in China where c.fr prices have increased. The first price increases on a c.fr basis came from Brazil in early February as the country's three key consumers all returned to the spot market at once. The buyers were, to an extent, forced to the market because of extended maintenance works at Santos port which will see the Termag terminal halting vessel operations from 28 February-29 March to perform its annual shore equipment maintenance followed by work at the Tiplam terminal. The lack of discharge flexibility pushed the buyers to step in to cover their demand in to early 2Q, at a time when spot availability for March loading cargoes was coming to an end. Prices increased to the mid-to-high-$60s/t c.fr.

In North Africa and India, c.fr prices have been static since the start of the year. When it comes to North Africa the stable pricing has been attributed to key end-users being covered by quarterly contract volumes and because Moroccan fertilizer producer OCP carried out maintenance in February on two granulation facilities at the same time as the company was consciously cutting its phosphate output because of weather-related problems at Jorf Lasfar port, causing problems with raw material arrivals and finished product loading. In India, whilst imports have been continuous, they have almost all been on a contract formula basis and, the increase in domestic sulphur production has also aided some buyers in avoiding the import spot market. Indian refiners will switch to producing Euro 6 fuels from Euro 4 on 1 April and this is of course increasing sulphur availability which is so far largely being directed to domestic consumers across all markets.

Finally, a look at the North American market where supply has also been tight. In the US, the commencement of the annual refinery maintenance season is limiting supply in hand with domestic refiners approaches to complying with IMO 2020 regulations having resulted in lower sulphur production rates. But the solid sulphur loading arm at the US Gulf port of Beaumont is now back in action. This is likely to increase exports and spot availability from the US Gulf in the future, but across February exports have been dedicated to fulfilling contract obligations. In Canada, logistical limitations because of strikes and demonstration action has hindered operations on the CN rail network across much of 2020 so far, lowering deliveries of sulphur to the port of Vancouver. Also, with prices still hovering at a maximum of mid-$40s/t f.o.b. Vancouver, plant-to-port delivery costs are still not feasible for all regional producers, keeping storage plans in action.

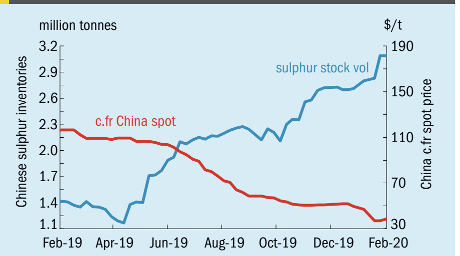

Fig. 1: **Chinese sulphur inventories (left axis) vs China c.fr spot price (right axis)**

Source: Argus Media

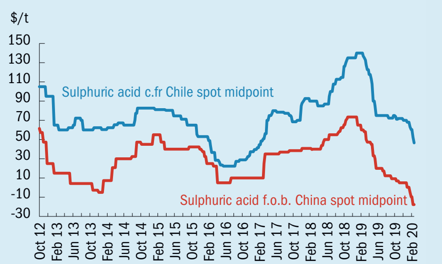

Fig. 2: **China f.o.b. and c.fr acid prices**

Source: Argus Media

SULPHURIC ACID

Sulphuric acid prices declined sharply across January-February on a c.fr and f.o.b. basis as sellers struggled to secure outlets for larger-than-expected prompt supply. The pressure came mostly from China, owing to the coronavirus outbreak, but sellers have also had fewer outlets than usual available as a result of a recent uptick in availability from non-traditional suppliers such as Indonesia and Australia. China's f.o.b. price dropped to negatives in early February for the first time since 4Q 2013, when at its lowest level it was assessed at -$10/t. As of 27 February, the f.o.b. price was already at -$20/t with little domestic end-user demand noted, and no clear time frame for many restarting operations despite encouragement by the Chinese government for industry to start returning to normal operations with easing coronavirus spread prevention measures.

South Korean and Japanese f.o.b. prices have followed that of China and slipped in to negative pricing in the first week of February before dropping by the end of the month to -$20/t. Whilst the price has fallen, unlike China's f.o.b. price, it has not yet dropped below the last record low of -$35/t f.o.b., which was encountered in the second quarter of 2016. Pressure has mounted in these two markets because of inventory increases in China in hand with swells at Japanese ports preventing some loading operations, forcing a build up in inventories there as well. But, as February came to an end, scheduling disruptions at ports lessened and spot sales to Chile helped ease inventory pressure.

In Chile, buyers of sulphuric acid have taken full advantage of softening f.o.b. prices and this has resulted in the country's c.fr price dropping by $17.5/t on a midpoint basis across January-February. Consumers have also been favouring vessels of greater than 30,000t because of attractive freight rates, even though such vessels usually require two port loadings. But demand has not been high from the country, which became the world's biggest sulphuric acid importer in 2019, with inventory levels high.

Turning to the US, of course prices here have also softened following the global trend. But, demand from the country has been firm across most of January and February, particularly with some supply disruptions in January in the west as strikes at the Asarco Hayden smelter kept the facility offline. Regular shipments from Europe and Asia have been satisfying US demand largely. Also, deliveries of Canadian sulphuric acid to the US has indeed been disrupted across the first few months of this year because of strikes followed by protests which blocked railroads. This led Chemtrade to announce in mid-February that the blockades could well have a material impact on the company's operations. But, given the complexity of the rail networks and the nature of the blockades it has been difficult to predict the extent of the disruption on the company's sites and third-party suppliers.

To conclude with Northwest Europe, contracts for the first quarter and first half settled mostly at a rollover with a slight reduction on the high end. Any increases in the first quarter contracts were achieved only on a freight basis, with higher rates seen on most routes and on the continent trucking costs had also increased. ■

Price Indications

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

Cash equivalent	September	October	November	December	January
Sulphur, bulk ($/t)					
Adnoc monthly contract	49	47	42	42	44
China c.fr spot	66	66	72	64	64
Liquid sulphur ($/t)					
Tampa f.o.b. contract	75	46	46	41	36
NW Europe c.fr	80	80	80	70	70
Sulphuric acid ($/t)					
US Gulf spot	75	75	75	75	74

Source: various

CONTENTS
What's in issue 387
COVER FEATURE 1
Kuwait's sulphur boost
COVER FEATURE 2
Sulphur in North America
COVER FEATURE 3
Redox reborn
COVER FEATURE 4
Better control in Claus plants

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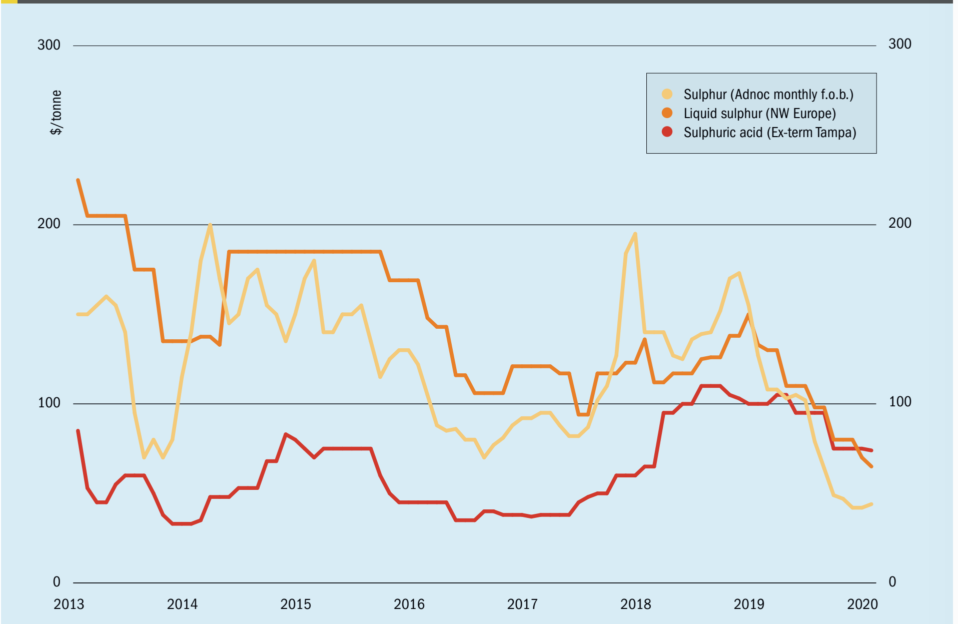
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

Historical price trends $/tonne



Source: BCInsight

SULPHUR

- Middle East supply will return to normal at the start of the second quarter with bottlenecks in the UAE and maintenance in Saudi Arabia at an end. But this is unlikely to result in lower Middle East f.o.b. prices until the second half of April, if not early May. This is because buyers who found it hard to find March loading cargoes will snap up any April product as soon as it's made available.
- Russian tonnes will return to the market in the second quarter with the opening of the Volga Don river system for the transportation season. But, all of this product will be directed to the North African and Latin American contract markets as supplier GazpromExport does not expect to have any sulphur for spot sale in 2Q. This will limit spot activity in the Black and Baltic Seas to small parcels of Russian sulphur from other suppliers and sulphur of Kazakh origin.
- The evolution and fallout of the coronavirus is still being monitored closely by the market and is the biggest market variable. The impact of the virus has had an influence on freight so far, pushing rates up on routes to China with ship owners less than enthusiastic to send vessels there because of quarantine policies. But, as the virus moves across the globe, rates on other key market routes will likely increase for the same reason, impacting both fob netbacks as well as c.fr prices.

SULPHURIC ACID

- There are mixed expectations as to if the floor has been met in Asian markets on both an f.o.b. and c.fr level. All eyes are on the Chinese market as any improvement in regional prices are only likely to come when logistics and the general supply chain in the country normalises. But a pause in price softening is expected in Asia in the very near term as significant volumes have recently been picked up on the spot market.
- Smelter acid has also been displacing burner production in some areas of the country where logistics have permitted it, but not to a great enough extent to reduce pressure on base metal producers completely.
- There are still further declines expected in the North American markets, especially considering the arbitrage opportunities which are currently open from Asia. But, if the region continues to look towards its more traditional supply markets, increasing freight rates between Europe and the US could slow c.fr price softening.
- The phosphates sector is of course still one of the biggest influencers no the market and in the long run, until there is a significant recovery, no real recovery will be felt in the sulphuric acid market. But stable to firm demand from the mining sector of the demand-side will mean that some regional prices will find intermittent support.

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Sulphur Industry News

UNITED ARAB EMIRATES

ADNOC issues Dalma offshore sour gas contracts

The Abu Dhabi National Oil Co. (ADNOC) has awarded two EPC contracts with a total value of more than $1.65 billion for the offshore Dalma sour gas development, 190 km northwest of Abu Dhabi city. Dalma is one of the fields in the offshore Ghasha ultra-sour gas concession, which ADNOC views as central to the UAE achieving self-sufficiency in domestic gas supplies.

The contracts went to Petrofac Emirates LLC and a joint venture between Petrofac and Sapura Energy. Both are due to be completed in 2022, with 70% of the total value set to flow into the UAE's economy under ADNOC's In-Country Value (ICV) programme.

Under the first contract, valued at $591 million over 30 months, Petrofac/Sapura Energy will engineer, procure, and construct three new wellhead platforms, removal and replacement of existing topsides, new pipelines, subsea umbilicals, composite and fibreoptic cables at the Hair Dalma, Satah, and Bu Haseer fields. The second, $1.065 billion contract, will see Petrofac become responsible for new gas conditioning facilities for gas dehydration, compression and associated utilities in Arzanah Island, 80 km from Abu Dhabi city. The treated gas will then be routed to the Habshan complex for further processing to deliver sales gas, condensate, and sulphur.

Dalma will produce 340 million cf/d and the Ghasha mega-project more than 1.5 bcf/d, when the latter comes onstream during the mid-2020s. According to ADNOC, Ghasha could supply close to 20% of the UAE's gas demand by the second half of this decade, and more than 120,000 bbl/d of oil and condensates once fully operational.

George Salibi, Petrofac's chief operating officer – engineering & construction (left), Yaser Saeed Almazrouei, executive director of ADNOC's upstream directorate, and Shahril Shamsuddin, president and group chief executive officer of Sapura Energy (right) at the signing ceremony.

Major discovery at Jebel Ali

A new gas discovery in the UAE will boost domestic supplies, although it is expected that the UAE will continue to be a gas importer via LNG and the Dolphin pipeline from Qatar. The huge shallow gas reservoir at Jebel Ali is estimated to hold up to 0 trillion cubic feet of gas, and is the world's biggest gas find since the discovery of the Galkynysh field in Turkmenistan in 2005. It covers an area of around 5,000 km² and is still in the early stages of appraisal. ADNOC made the discovery on the border between the Emirates of Dubai and Abu Dhabi, and will develop it jointly with the Dubai Supply Authority (DUSUP), with gas from the field to flow to Dubai via DUSUP to feed utilities and industrial companies. Dubai has no gas of its own and imports 2 bcf/d of gas from Qatar as well as additional volumes imported as LNG, although the start-up of new coal and solar power projects will lower gas requirements in 2021. Total gas production in the UAE (mainly from Abu Dhabi) is around 6.2 bcf/d, while gas consumption is around 7.4 bcf/d, although exploitation of the new reserve could see gas self-sufficiency by 2030.

The discovery comes after Eni and the UAE's Sharjah National Oil Corp. made another find recently, with gas and condensates flowing from a test well in Sharjah, the first onshore Sharjah discovery in 37 years.

ROMANIA

Petrom switches to LSFO production

Romania's OMV Petrom has started production of 0.5% sulphur content low sulphur fuel oil (LSFO)at its Petrobrazi refinery in Romania to meet the new IMO 2020 fuel specifications. The production follows a €3 million ($3.2 million) upgrade of the refinery for it to produce70,000 t/a of low sulphur bunker fuel, relieving a Romanian market heavily reliant on imports.

"The new marine fuel oil obtained at the Petrobrazi refinery has only up to 0.5% sulphur content, in line with the IMO global sulphur limit applicable to the shipping industry starting from this year," OMV Petrom stated. "OMV Petrom supports the maritime transport industry with a sustainable solution, both economically, as well as from the perspective of environmental protection. According to IMO, by limiting the sulphur content in ships' fuel oil to 0.5%, an annual 77% drop in sulphur emissions can be achieved, which means a reduction of 8.5 million metric tonnes of sulphur dioxide per year globally. This will have a positive impact on quality of life in the communities of the port and coastal cities."

SPAIN

IPCO buys Ingeniera de Procesos

IPCO has acquired Spanish company Ingeniera de Procesos SA (IdP), a supplier of processing equipment and spare parts, primarily to the chemical and sulphur industries. For the past 30 years, IdP had had an existing agreement with IPCO giving them the exclusive right to sell chemical and sulphur equipment in Spain based on IPCO's steel belts and Rotoform machines.

"The acquisition is well in line with IPCO's long-term strategy for profitable growth. With this, we strengthen our presence in the Spanish market and get access to a large installed base and direct contact with the customers", says Johan Sjögren, Managing Director IPCO Equipment Division.

CANADA

Strategic Oil and Gas goes into receivership

Alberta-based Strategic Oil and Gas Ltd had gone into receivership after failing to agree a restructuring plan. The company owns gas wells in the Northwest Territory, including the Cameron Hills sour gas field, which is subject to ongoing end of life clean-up costs, including a remediation order because of leaks of hydrogen sulphide from the I-73 well. Strategic had installed a sour gas scrubber as a temporary measure prior to a permanent fix being in place by the deadline of April 1st. It is part of an ongoing issue for provincial authorities in Canada, where 'financially fragile' operators are trying to deal with the clean-up costs of spent oil and gas wells and oil sands patches, potentially amounting to billions of dollars. There is a continuing concern that companies will buy up good assets from struggling owners, leaving clean-up costs for the poor assets as a liability for the taxpayer.

UNITED STATES

Online platform for improved plant performance

ExxonMobil has launched an online platform called *InFocus* to help customers optimise plant performance, increase operational efficiency and minimise production interruptions. The company says that, using secure, near-real-time data, operators will be able to make faster, more informed decisions and collaborate more easily with ExxonMobil technical support. The platform has been tested and piloted with early adopters and has already been fully deployed in multiple facilities.

The platform provides two solutions; the predictive tool enables users to test the impact of feedstock and operational changes on lube product yields and quality. Developed from years of ExxonMobil expertise and experience, the tool can also be tuned to match actual unit performance, delivering valuable data enabling users to evaluate feed flexibility, optimise product mix and maximise operational value. The *InFocus* unit monitoring tool enables timely technical insights to improve process performance.

"Our customers are under increasing pressure to improve profitability and be more efficient," said Dan Moore, president of ExxonMobil Catalysts and Licensing. "Our *InFocus* Platform will provide deeper insight into their operations and will enable concrete recommendations on ways to optimise plant performance and minimise interruptions."

Plume suppression system for wet scrubbing

DuPont Clean Technologies has introduced a new steam plume suppression solution for its *MECS® DynaWave®* scrubbers in sulphur recovery unit (SRU) applications. The *Sennuba™* plume suppression technology employs two heat exchangers and a heat transfer medium to heat stack gas from the wet scrubbers that are used to remove pollutants from flue gases, with steam produced with the heat of the gas at the inlet of those scrubbers. This avoids the high operating costs associated with other methods of steam plume control, as it recovers otherwise lost heat from the process to generate the necessary steam to suppress the visible plume. *Sennuba* is designed with a heat transfer medium so there is no chance of leakage of the process gas directly to the stack gas. In this design, there is no forced circulation of the heat transfer medium.

CONTENTS

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Weir Minerals launches three new pumps

PHOTO: WEIR MINERALS

The Lewis vertical high pressure molten salt pump.

Weir Minerals has launched three additions to its *Lewis*® range of pumps and valves for the sulphur, sulphuric and phosphoric acid industries. The three pumps have been designed to maximise wear life in some of the most corrosive industrial applications while simplifying maintenance through their streamlined designs. This has significantly reduced the number of parts compared to previous pumps, without compromising their performance.

"Although they're designed to address different challenges, these three new pumps were guided by the same core design principles: using advances in material technology to achieve increased performance and wear life, while reducing complexity to simplify equipment maintenance and give us the flexibility to deliver more engineered to order features that benefit our customers," said Jerry Ernsky, Lewis product manager, Weir Minerals.

The first is the new Lewis horizontal process pump, which combines the corrosion and wear resistance of *Lewmet*® alloys with the robust performance, efficiency and ease of maintenance associated with centrifugal pumps. This single stage, end suction horizontal process pump is suitable for a wide variety of chemical processing applications.

The new *Lewis VL* Axial Flow Pump has heavy duty construction for use in corrosive, high temperature chemical processing applications such as evaporator and crystalliser circulation. Its innovative design can be customised to suit a wide variety of industrial applications, while its low component count makes servicing quicker and easier.

Finally, the *Lewis* vertical high pressure molten salt pump has been designed to meet the needs of the burgeoning concentrated solar power (CSP) industry. A multi-stage vertical turbine pump, it has been designed to handle the multifaceted challenges associated with the extremely high pressures and temperatures associated with pumping molten salt for thermal energy storage. It can be expanded from 3 to 14 stages, and has an integrated protective thermal barrier, a non-contracting shaft seal and a low NPSH first stage.

All three pumps are constructed with Weir Minerals' *Lewmet* alloys, which incorporate specialised metallurgy designed to survive in the most corrosive industrial applications involving sulphur, sulphuric and phosphoric acids.

Alkylation unit contract awarded

DuPont has also been awarded the contract to supply Next Wave Energy Partners with licensing, engineering and proprietary equipment for a *STRATCO*® alkylation unit near the Houston Ship Channel in Pasadena, Texas, known as Project Traveler. In order to meet North America's growing octane demand and desire for cleaner-burning gasoline, Next Wave commissioned DuPont to supply a 28,000 bbl/d alkylation unit from an ethylene feedstock. Start-up is targeted for mid-2022. *STRATCO* alkylation technology is a sulphuric acid catalysed process with over 100 units licensed worldwide and more than 915,000 bbl/d of installed capacity.

"DuPont is excited to provide Next Wave with our *STRATCO* alkylation technology in the world's first stand-alone alkylation complex," said Kevin Bockwinkel, Global Licensing Business Manager, *STRATCO* Alkylation Technology. Dan Fahey, Next Wave Vice President, Engineering & Technology, commented; "We value the relationship and technical contributions by DuPont over the last several years to progress our project to final investment decision."

SAUDI ARABIA

Construction complete on Fadhili gas plant

Press reports say that engineering, procurement and construction (EPC) work on Saudi Aramco's Fadhbili sour gas processing plant were completed in December 2019. The plan, located 30km southwest of the Khursaniyah gas plant in the east of Saudi Arabia, has been built at a cost of $6.5 billion. Tecnicas Reunidas built the central gas processing facility, and the utilities and interconnecting systems, with UK-based Petrofac constructing six sulphur recovery trains with associated facilities for sulphur and heavy duty oil handling, loading, unloading and storage, as well as a sour water stripper, flare system and waste water treatment plant. Pipelines and other utilities were built by Larsen & Toubro, Arkad Engineering & Construction, Denys Arabia and Al-Muhaidib Contracting. The front-end engineering and design (FEED) work was carried out by the UK-headquartered Wood Group, which was also the project management consultant.

When at capacity the Fadhili plant will process 2 billion scf/d of non-associated gas from the Hasbah offshore fields and 0.5 billion scf/d of non-associated gas from the Khursaniyah onshore fields to produce 1.5 billion scf/d of sales gas and 4,000 t/d of recovered sulphur.

The Fadhili gas plant.

PHOTO: SAUDI ARAMCO

Sulphuric Acid News

CHINA

Coronavirus stoppages leading to acid build-up

China's copper industry is facing difficulties caused by the coronavirus outbreak in the country. Prolonged factory closures, particularly in Hubei province, at the centre of the outbreak, as well as neighbouring Guangdong and Zhejiang, also badly affected, have caused a slump in demand for copper domestically as copper fabricators remain on extended closure. However, smelters have resisted cutting production. Daye Nonferrous, based in Huangshi at the centre of coronavirus outbreak, continues to operate at 80% of its 600,000 t/a capacity for 1Q 2020, according to the company, in spite of quarantine and transport restrictions which have reduced truck shipments to the smelter – Daye is reportedly still able to receive copper concentrate shipments via the Yangtze River to Huangshi port.

China produced 17.15 million tonnes of copper fabricated products in 2018 – 76% of the world's total, according to the World Bureau of Metal Statistics, and in the absence of local demand inventories are reportedly building up at smelter plants and sea ports. A bigger headache has been what to do with the large quantities of sulphuric acid from the still operating copper, zinc and lead smelters. Hubei province, now mostly on lockdown, consumes over 20 million t/a of domestic sulfuric acid output in China, representing about 20% of total consumption, in the production of fertilizers and chemicals.

PHOTO: GCT

GCT's phosphate plant at Gafsa.

TUNISIA

Phosphate production rose 46% during 2019

Tunisia's national production of phosphates reached 4.1 million t/a in 2019, up 46% from 2018, according to figures released by the Tunisian industry ministry. The ministry said that phosphate production for the period 2017-2019 averaged 3.6 million t/a, 20% up on the average of 3.0 million t/a for the period 2011-2016. It also claimed that phosphate production is now running at an average of 15,000 t/d, an average of 5.0-5.4 million t/a if sustained over the whole year. These figures however disguise the fact that 2018 was a low point for Tunisian phosphate production due to industrial disruption.

Tunisia's phosphate output has been languishing since the Arab Spring and the overthrow of former president Zine El Abidine Ben Ali. Prior to 2011 Tunisian phosphate production averaged 8.0 million t/a and the country was the fifth largest exporter in the world. However, the 2011 revolution came as a result of chronic unemployment and poverty, especially in the Gafsa region that is the source of the nation's phosphate reserves, where unemployment reached 30%. To try and cure ameliorate this the new government forced Compagnie des Phosphates de Gafsa (CPG) to 'hire' more than 18,000 'ghost' workers without providing jobs for them. The company's workforce has more than tripled to 30,000 since 2011. Lack of transparency in the hiring process however led to strikes and sit-ins that blocked the gates of the company and saw output fall from 500,000 tonnes per month to 150,000 tonnes in January 2018. Meanwhile, the additional cost burden has seen CPG losing $1 billion per year and heading towards bankruptcy.

A vote in February has created a coalition government which has now to try and tackle low growth, unemployment, government deficits, high inflation and deteriorating public services, as well as negotiating an IMF bailout. In spite of this, the government says that phosphate production is finallyheading in the right direction and could reach 6 million t/a in 2020, bringing a badly needed additional $350 million to the government's coffers and adding 1% to GDP.

INDIA

Symposium on sulphuric acid technology

In January DuPont Clean Technologies (DuPont) held a Sulphuric Acid Symposium in Hyderabad to share the latest intelligence on new technologies, operations and equipment that enable sulphuric plant operators to raise productivity and reduce operating costs. Keynote speeches addressed topics that are of common concern and interest to the industry ranging from emissions reduction to life cycle costs, safety and troubleshooting.

The two-day symposium gave delegates insight into emissions reduction technologies including an innovative new catalyst, discussed materials, processes, systems and services that are designed to improve sulphuric acid plant productivity, examined the behaviour of alloys in acid towers and converters, shared tips on troubleshooting and also presented personal protective equipment against chemical influences. In eight keynote sessions, technical specialists shared details on the latest technologies and equipment and answered delegate questions in a closing roundtable discussion.

SULPHUR
ISSUE 387
MARCH-APRIL 2020

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Thierry Marin, Managing Director, DuPont Clean Technologies, EMEA, explained, "DuPont Clean Technologies regularly holds similar events around the world to allow members of the sulphuric acid industry to stay up to date with the latest technology developments and best sulfuric acid operational practices. These workshops give them the opportunity to discuss technical questions that are based on their own experiences with MECS subject matter experts and to make us aware of their particular objectives and requirements relating to emissions reduction and production optimisation."

New acid plant up and running

Indian pulp and paper manufacturer Bhageria Industries Limited says that it has completed commissioning of its new sulphuric acid plant at the Tarapur Boisar Induatrial Area, Boisar Palghar in Maharashtra state. Commercial production began in February, according to the company's statement to the Indian Bourse. The Maharashtra Pollution Control Board has issued permits for the manufacture of 150 t/d of sulphuric acid, as well as 10 t/d of 25% oleum, 30 t/d of 65% oleum, and 30 t/d of concentrated sulphuric acid. The facility is backward integrated in the company's production, and the $3.6 million cost was funded internally.

ITALY

Italmach acquires phosphate recovery technology

Italmatch Chemicals has acquired the RecoPhos technology from Israel Chemicals (ICL), including all licenses, IP, know-how and assets related to it. The company says that its aim is to further develop and complete a sustainable, efficient and economically viable process to recover phosphorus from all phosphorus-containing waste streams, such as sewage sludge or ashes, to produce elemental phosphorus (P_4). Italmatch's historical and current portfolio is strongly related to phosphorus as a strategic raw material, and says that the new technology will open a new route to produce pure elemental phosphorus from secondary waste raw materials, contributing to reducing the consumption of natural phosphate ore.

Sergio Iorio, CEO of Italmatch Chemicals Group, said: "for Italmatch, innovation and sustainability represent the key factor for the company's long-term success… this transaction is completely based on the concept of 'circularity' of resources rather than the exploitation of new ones."

PHOTO: AURUBIS

The gas cleaning section at the Pirdop smelter.

Carlos Galeano, Beyond Innovation Project Director, stated: "This acquisition not only introduces a new way to treat waste streams containing phosphorus, but also transforms the way the industry will treat phosphorus- containing ashes in the future. With *RecoPhos*, Italmatch Chemicals aims to both offer P_4 with considerably higher quality to the market and consolidate its global leadership."

BULGARIA

Acid output rises at Pirdop

Hamburg-based Aurubis said that the copper concentrate throughput of its Bulgarian smelter at Pirdop near Sofia rose by a 3% year on year to 333,000 tonnes in the first quarter of its fiscal year 2019/2020 (beginning on October 1st 2019), after boiler damage had affected output in the previous quarter. Copper cathode output at Pirdop remained unchanged year-on-year at 55,000 tonnes for the October-December period of 2019, the company said in an interim financial statement. Sulfuric acid output at Pirdop amounted to 337,000 tonnes in the review period, 12% higher on the same quarter of the previous year.

DEMOCRATIC REPUBLIC OF CONGO

Acid plant to commission in 1H 2020

In an update on its major projects, Katanga Mining Limited said that the sulphuric acid plant project at its 75%-owned subsidiary the Kamoto Copper Company (KCC) would be commissioned during the first half of 2020. Copper cathode production increased to 65,400 tonnes in Q4 2019 from 59,424 tonnes in Q3 2019. Cobalt contained in hydroxide production increased to 6,173 tonnes in Q4 2019 from 4,763 tonnes in Q3 2019, but KCC temporarily suspended the export and sale of cobalt due to the presence of uranium being detected in the cobalt hydroxide at levels that exceed the acceptable limit allowed for export. The company stressed that the low levels of radioactivity detected in the uranium to date do not present a health and safety risk, and Katanga Mining, together with KCC's other 25% shareholder, DRC state-owned La Générale des Carrières et des Mines (Gécamines), has been working with the Ministry of Mines and the Congolese Atomic Energy Agency on a long-term technical solution to the uranium inclusion in the form of an ion exchange plant. Whole ore leach modelling has been completed which indicates that current and 'elevated' uranium levels may be successfully removed from the cobalt hydroxide using phosphoric acid, and the leaching project is currently subject to a feasibility study.

MOROCCO

Phosphate shipments from Boucraa fall

Moroccan state phosphate giant OCP's exports of phosphates from the Boucraa mine in Western Sahara dropped to their lowest level since 2012 last year, with volumes falling from 1.9 million t/a in 2018 to 1.0 million t/a in 2019. The average figure for 2012-2018 was 1.8 million t/a, against a capacity of 2.6 million t/a. Western Saharan separatists have claimed that the fall followed court cases brought against OCP in South Africa and Panama in 2017 involving the detention of phosphate-carrying vessels, instigated by the Polisario independence movement, and a halt to sales to North America in December 2018, previously one of OCP's largest overseas markets, taking 900,000 t/a of phosphate rock. New Zealand has also seen court action to halt the imports of Moroccan phosphate from Western Sahara. However, while OCP acknowledged that exports from Boucraa fell between 2018 and 2019, the company said this was in line with a "global decline in demand for phosphate rock" and was "mainly caused by the termination of a contract with one of our clients, who decided to repurpose two of its phosphate plants for strategic reasons and focus on nitrogen and potash-based products."

The company said that it remained confident in its Boucraa operations and that it is continuing to make investments in an integrated fertilizer complex at the port of Laayoune in Western Sahara at a cost of $2 billion.

CHILE

Phosphate project now clear to move ahead

Canada's Lara Exploration says that it has been informed by its subsidiary Bifox Ltd that the latter has now completed agreements with the Chilean government to settle outstanding environmental infractions and fines incurred by the vendors and lift the embargo on mining and processing at the Bifox Phosphate Project at Copiapó, in Chile's northern Atacama desert. Bifox says that it has also begun the application process with the Servicio Nacional de Geología y Minería to reinstate its operating permits and restart mining. During the first quarter of 2020, the company plans to start processing existing stockpiles of phosphate rock and complete further plant upgrades, and then, once permits are in place, resume mining and production at an initial rate of 5,000 tonnes per month, ramping up over time to 20,000 tonnes per month.

Bifox rock has been undergoing field trials at the University of Lujan in Argentina, to measure its efficiency as a direct application fertilizer. The company says that the testing also confirmed the rock is conducive to production of both triple superphosphate (TSP) and single superphosphate (SSP). Bifox has also retained the Florida Industrial and Phosphate Research Institute to test and confirm the process for

PHOTO: CANADIAN INSTITUTE OF MINING

The Grasberg mine, Indonesia.

conversion of Bifox phosphate rock into SSP and trials to produce a specialty product: partially acidulated phosphate rock (PAPR). The testing is expected to also provide capital cost estimates for the SSP and PAPR plants.

INDONESIA

New smelter to begin construction in August

Freeport Indonesia says that front end engineering and design on the company's new $3 billion copper smelter in East Java has been completed, and site preparation is expected to be finished by June, with construction works beginning in August 2020. Construction of a smelter is part of parent company Freeport-McMoran's deal with the Indonesian government to maintain its mining rights at Grasberg, the world's second biggest copper mine, until 2041. Freeport says that it is on course to finish the smelter by the end of December 2023. The smelter is expected to consume 2.0 million t/a of copper concentrate and produce between 500,000 t/a to 600,000 t/a of copper. Meanwhile, the company has started to transition to underground mining at Grasberg in Indonesia's Papua province, which is expected to affect its copper output. Output from the mine in 2020 is expected at around 50% of its normal level of 210,000 t/d of ore, with output to return to normal in 2022.

Freeport Indonesia currently produces about 3 million t/a of copper concentrate, 1 million t/a of which is processed by Smelting, a joint venture with Japan's Mitsubishi in Gresik. Smelting produces 291,000 t/a of copper cathode, as well as 1.04 million t/a of sulphuric acid.

SULPHUR
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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

Charlotte Hebebrand, Director General of the International Fertilizer Industry Association (IFA), will end her term with the organisation on May 1st. IFA's Senior Director of the Agriculture Service, **Patrick Heffer**, will serve as interim Director General as of 1 May, until a new permanent Director General can be proposed by IFA's Board of Directors and approved by the membership at the organisation's General Meeting, with the aim of having a new person in place by July.

In a farewell letter to IFA's membership, Charlotte said that it had been "a tremendous privilege" to work with IFA since joining the association in September 2012. "I will forever be grateful for the trust you placed in me, for your engagement to both build and implement IFA's strategic objectives, and for all the support you have provided to IFA," she said. "IFA is a dynamic and vibrant association for a crucially important industry in a fast changing world, and we have a terrific Secretariat and outstanding senior staff, which will ensure a smooth transition. I am very pleased that I will continue to be closely involved in IFA affairs, as I assume my next post as EVP at Nutrien, pending work authorization from immigration authorities, and will be delighted to remain in touch with all of you."

The board of directors of Haldor Topsoe has announced the appointment of **Roeland Baan** as the company's new Chief Executive Officer (CEO) as from June 1st, 2020. Baan takes over from **Bjerne S. Clausen**, who will retire in June after more than 40 years with the company, including more than eight years as CEO. Since 2016, Roeland Baan has been President and CEO of the global stainless steel company Outokumpu. Previously, he held a wide range of global CEO and executive vice president (EVP) positions at Aleris International, Arcelor Mittal, SHV NV and Shell. He is Vice Chairman of the International Stainless Steel Forum and member of the Executive Committee of Eurofer. He also serves as a supervisory board member of SBM Offshore NV and as an independent board member of Norsk Hydro ASA. Mr. Baan is a citizen of The Netherlands and holds a MSc in Economics from Vrije Universiteit Amsterdam.

"I am delighted to announce Roeland Baan as new CEO of Haldor Topsoe A/S. He has remarkable global experience and a proven track record of driving growth, developing businesses and building cohesive organizations. I am convinced he will contribute to the continued strong performance of Haldor Topsoe. Topsoe is a profitable company with a solid core business. With Roeland's direction, we will continue to focus on being global leader in the markets in which we operate," said Jeppe Christiansen, Chairman of the Board of Directors of Haldor Topsoe A/S.

"I would also like to take this opportunity to thank Bjerne S. Clausen for his contribution and dedicated work during his more than 40 years with the company. Bjerne is retiring after an impressive career. As a scientist and leader, he has been a defining figure in both Topsoe's technological and commercial development. As CEO, Bjerne has played an instrumental role in making Haldor Topsoe the focused and profitable company it is today".

Bjerne S. Clausen commented: "I have had an amazing journey here at Topsoe, worked on a vast variety of exciting projects, worked with some of the sharpest brains in the field of catalysis and chemistry, and met customers and partners around the globe. I cannot imagine a more rewarding career. I welcome Roeland Baan to the company. He has come to a great company with dedicated and passionate colleagues."

Calendar 2020

MARCH

22-24
AFPM Annual Meeting, AUSTIN, Texas, USA
Contact: American Fuel and Petrochemical Manufacturers (AFPM)
1667 K Street, NW, Suite 700,
Washington, DC 20006, USA
Tel: +1 202 457 0480
Email: meetings@afpm.org
Web: www.afpm.org

APRIL

5-8
2020 Australasia Sulfuric Acid Workshop, BRISBANE, Australia
Contact: Kathy Hayward, Sulfuric Acid Today
Email: kathy@h2so4today.com
Web: www.acidworkshop.com

13-16
Sour Oil and Gas Advanced Technologies (SOGAT) 2020, ABU DHABI, UAE
Contact: Nick Coles, Director of conferences, Dome Exhibitions
Tel : +971 2 674 4040
Fax: +971 2 672 1217
Email: nick@domeexhibitions.com

20-22
IFA 88th Annual Conference, NEW DELHI, India
Contact: IFA secretariat
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

22-24
The Sulphur Institute Sulphur World Symposium, CHICAGO, Illinois, USA
Contact: Sarah Amirie, TSI
Tel: +1 202 296 2971
Email: SAmirie@sulphurinstitute.org

MAY

11-15
RefComm Galveston 2020, GALVESTON, Texas, USA
Contact: Refining Community
Tel: +1 360 966 7251
Web: www.refiningcommunity.com/refcomm-galveston-2020/

JUNE

12-13
44th Annual International Phosphate Fertilizer and Sulphuric Acid Technology Conference, CLEARWATER, Florida, USA
Contact: Miguel Bravo, AIChE Central Florida Section
Email: vicechair@aiche-cf.org
Web: aiche-cf.org/Clearwater_Conference

JULY

13-17
Brimstone Amine Treating and Sour Water Stripping Course, HOUSTON, Texas, USA
Contact: Mike Anderson, Brimstone STS
Tel: +1 909 597 3249
Email: mike.anderson@brimstone-sts.com
Web: www.brimstone-sts.com

SEPTEMBER

21-25
Brimstone Sulphur Recovery Fundamentals Course, HOUSTON, Texas, USA
Contact: Mike Anderson, Brimstone STS
Tel: +1 909 597 3249
Email: mike.anderson@brimstone-sts.com
Web: www.brimstone-sts.com

OCTOBER

7-8
TiO2 World Summit, CLEVELAND, Ohio, USA
Contact: Shannon Siegferth, Smithers
Tel: +1 330 762 7441
Email: ssiegferth@smithers.com

NOVEMBER

2-4
Sulphur and Sulphuric Acid Conference 2020, THE HAGUE, Netherlands,
Contact: CRU Events
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

CONTENTS

SULPHUR
ISSUE 387
MARCH-APRIL 2020

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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

Kuwait's sulphur boost

Kuwait is in the middle of a major overhaul and expansion of its refining capacity, as well as boosting LPG output and sour gas processing.

The tank farm at Mina Al-Ahmadi.

Fig. 1: **Kuwait's oil and gas industry**

Kuwait's history in oil and gas development dates back to 1938, when oil was first discovered in the Kingdom at the Burgan oil field. Initially the Kuwait Oil Company (KOC) was owned by Anglo-Persian Oil (later to become BP), but the Kuwaiti government gradually increased its stake in the company over the decades until by 1976 it was 100% state owned. In 1960 the Kuwait Petroleum Company (KPC) was formed as a state entity to own and operate all of the various subsidiaries – the Kuwait Oil Company, which deals with exploration and production; Kuwait National Petroleum Company (KNPC), which handles oil refining, gas liquefaction and domestic fuel distribution; Kuwait Oil Tanker Company (KOTC) which manages seaborne exports; and the Petrochemical Industries Company (PIC), which manages downstream operations.

Kuwait holds around 100 billion barrels of oil reserves, about 6% of the world's total and the seventh largest reserve in the world. This includes about 5 billion barrels in the Neutral Zone shared with Saudi Arabia. Oil production of around 2.7-3.0 million barrels per day has not changed materially in the past decade, and the country's reserves have likewise stayed fairly constant over the past two decades. Most of the production comes from mature oil fields discovered in the 1930s and 1950s, particularly the Burgan field in the southeast of the country, which produces around 1.7 million bbl/d. Other large fields are in the north of the country, including Raudhatain (350,000 bbl/d), Sabriya (100,000 bbl/d), Ratqa and Abdali (75,000 bbl/d total).

Production from the Neutral Zone shared with Saudi Arabia was shut down in 2014-15 over a dispute over development plans for the various fields, and has not resumed since. However, the two countries began serious negotiations to end the dispute last year, and reached an agreement in December 2019. As a result, production is expected to restart soon and begin slowly ramping up through 2020, reaching 500,000 bbl/d by the end of the year, split evenly between Kuwait and Saudi Arabia.

Domestic oil consumption is relatively limited, at about 455,000 bbl/d in 2018, mostly to feed domestic refineries. The rest of Kuwait's crude is exported, mainly to Asia.

As with oil, gas reserves have likewise remained fairly constant over the past decade at around 1.7 trillion cubic metres. Gas production was 17.5 bcm in 2018 according to BP, falling some way short of consumption of 21.8 bcm that year, and leading to Kuwait having to import natural gas as LNG. While some of Kuwait's gas reserves is associated gas in oil fields, where the rate of exploitation is limited by Kuwait's OPEC quotas, there are large reserves of non-associated gas in the north of the country, although these reserves are more geologically complex, in tight or sour gas deposits, and hence they have so far not seen any significant exploitation. Currently about 80% of Kuwait's gas production comes from associated gas.

Project Kuwait

Project Kuwait was a scheme first proposed in 1997 to increase the country's oil production capacity and its reliance on the ageing Burgan oil field. However, the project involved exploitation of the country's northern heavy oil field, including the Jurassic field and an expansion at Ratqa, as well as additional offshore oil production, and the resulting technical challenges meant that there would be reliance upon the involvement of overseas project partners to bring the relevant technology to tackle the very sour oil and gas that would be produced. The country's parliament was adamantly opposed to the principle of foreign ownership of Kuwait's oil sector, and so the project has slipped and slipped.

In 2010, Shell signed an enhanced technical services agreement (ETSA) to help develop the Jurassic gas fields; but the deal was held up by parliamentary and judicial inquiries until 2016, when KPC amended the ETSA and awarded contracts to both BP and Shell.

Project Kuwait was originally to have taken oil output to 4 million bbl/d by 2020. The country's revised strategy is now aiming to raise crude production to 4.75 million bbl/d by 2040, and natural gas production to 2.5 bcf/d (from its current 630,000 scf/d) by 2040, via the development of the Jurassic fields in the north. There are also plans to expand downstream operations, including refining and petrochemical production. The largest expansion in the refining sector is coming from the 615,000 bbl/d Al Zour refinery, as well as the Clean Fuels Project expansion of two of the existing refineries; Mina Al-Ahmadi and Mina Abdullah.

Mina Abdullah refinery.

Mina Al Ahmadi

Mina Al-Ahmadi (MAA) refinery is sited 45 km to the south of Kuwait City on the Gulf coast. It was originally built in 1949 as a simple 25,000 bbl/d refinery to supply the local market. When the refinery became part of KNPC in the 1980s, two major expansion programmes increased capacity drastically to 460,000 bbl/d, via the addition of 290,000 bbl/d of crude distillation capacity, and a fluid catalytic cracker. Part of the expansion programme added sulphur recovery capacity via four units with a total capacity of 1,334 t/d of granulated sulphur.

As well as the refinery, MAA also has an LPG liquefaction plant dating back to 1978, which produces propane, butane and natural gasoline, in addition to lean gas and residues. The gas plant was built to process all associated gas/condensates collected from KOC operations. It consists of three identical trains with a total processing capacity of 1.68 billion scf/d, including 80,000 bbl/d of hydrocarbon condensate. In 2000, the acid gas removal project was implemented to treat associated sour gas from oil fields, and in 2002, in order to meet latest diesel standards, a new gasoil desulphurisation unit was added to the refinery.

Mina Abdullah refinery

Mina Abdullah, 60km south of Kuwait City, was built in 1958 by US independent oil company AMINOIL, and had an original capacity of 30,000 bbl/d. Following several expansion projects between 1962-1967 its refining capacity rose to approximately 145,000 bbl/d. Ownership was transferred to KNPC in 1978. It was modernised during the 1980s as part of the same project to revamp Mina Al Ahmadi, and capacity was increased again, to 230,000 bbl/d. The refinery was damaged during the Iraqi invasion in 1989, and after this the government took the opportunity of repairing the damage to debottleneck capacity to 270,000 bbl/d. The refinery has a delayed coker – the only one in the Gulf region, as well as naptha, diesel and kerosene hydrotreaters and a hydrocracker. There is also an offshore island for tanker loading. Sulphur recovery is 99.9% from the amine regenerator acid gas, sour water stripper overhead gas and the recycle gas from the tail gas treating unit (TGTU). The recovered molten sulphur is degassed and sent to flaking facilities located in MAA, while the tail gas is sent to the TGTU for further processing. The unit consists of three identical trains, each with a sulphur capacity of about 270 t/d. In 2004 capacity of each unit was increased to 400 t/d using oxygen enrichment.

Shuaiba refinery

There was a third refinery, at Shuaiba, 50 km south of Kuwait City, dating back

SULPHUR
ISSUE 387
MARCH-APRIL 2020

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to 1968. At its peak the refinery had a capacity of 200,000 bbl/d. As it was the world's first all-hydrogen refinery, Shuaiba could process relatively high sulphur heavy crudes. This provided the facility with the flexibility to produce high quality products for export to international markets. However, while Mina Al Ahmadi and Mina Abdullah refineries had space for expansion and the addition of extra units, Shuaiba did not, and so the main refinery was closed in April 2017 as part of the Clean Fuels Project improvements – the Clean Fuels Project would instead use Shuaiba's storage tanks and export facilities.

The Clean Fuels Project

In 2015 Kuwait began a $16 billion strategic project to expand and upgrade both the Mina Abdullah and Mina Al-Ahmadi refineries to be an integrated refining complex with a total capacity of 800,000 bbl/d (up from the previous combined total of 730,000 bbl/d) by increasing MAA output to 346,000 bbl/d and Mina Abdullah to 546,000 bbl/d. The project will also increase the output of products meeting Euro-5 quality standards (10 ppm sulphur) and enhance operating efficiency. The initial schedule envisaged completion in late 2017, but the project has faced delays – heavy rain in November 2018 flooded the refinery and caused damage to an area under the public road, for example. Some units came on-stream during 2019, but at the end of last year lead contractor JGC from Japan said that full project completion would now be towards the end of 2020.

Al Zour refinery

In addition to the Clean Fuels Project, Kuwait is significantly expanding its refining capacity via the construction of a new grassroots facility at Al Zour. The Al-Zour refinery will process up to 650,000 bbl/d of heavy and igh sulphur Kuwait crudes to produce high value products and fuel oil, and includes a hydroskimming facility which can be upgrade to a full conversion refinery. Sulphur recovery will by 99.9% via six SRU trains, with a total sulphur capacity of 600,000 t/a.

Fifth gas train

The gas processing facilities at Mina Al Ahmadi are also being expanded to cope with an anticipated increase in non-associated gas from the Jurassic and Dorra gas fields, as well as feeds from KNPC refineries. The methane will be fed to power stations, propane and butane sent for domestic use, and ethane will go to olefins production. Propane, butane and pentane will also be exported. Overall the fifth gas train will produce 805 million scf/d of sales gas and 106,000 bbl/d of condensate, taking total gas processing capacity at the site to 3.2 billion scf/d. The $1.4 billion project was mechanically completed in July 2019, with trial production beginning in late 2019 and full operation expected by Q1 2020.


PHOTO: KPC

Sulphur storage at Mina Al-Ahmadi.

Upgraded sulphur facility

The expanded gas processing capacity at Mina Al Ahmadi has also necessitated an upgrade to the sulphur processing facility at the site. The upgrade includes boosting ship loading capacity to 1,500 t/h and the addition of a new pier giving the facility the ability to handle larger vessels up to 60,000 dwt, as well as additional liquid sulphur storage tanks and solidification units. The first phase of the upgrade project was completed at the end of 2017, with final completion in late 2019. Liquid sulphur storage has been increased by 19,000 tonnes in four tanks, and there are now five sulphur granulation units with a total capacity of 5,000 t/d. There is also 145,000 tonnes of covered solid sulphur storage capacity.

Kuwait's sulphur output

At present Kuwait produces around 750,000 t/a of sulphur. However, this is set to rise to 2.5 million t/a with the addition of the 600,000 t/a from the Al Zour refinery, and 1.2 million t/a from Mina Al Ahmadi and Mina Abdullah, including the Clean Fuels Project and fifth gas train. The current timeline for these will see the Clean Fuels Project complete by the end of 2020 and a start-up for the Al Zour refinery in mid-2021. This would see Kuwait producing 2.5 million t/a of sulphur by 2022. With little local demand, most of this will be available for export. According to KPC, one of the consequences of this has been a move by Kuwait to monthly sulphur pricing, following in the wake of ADNOC in Abu Dhabi and Muntajat in Qatar. KPC argued at the Sulphur conference in November 2019 that quarterly sulphur pricing involves too great a time lag in the more volatile sulphur market that we are currently seeing.

Kuwait's additional sulphur production forms part of a more general increase in output from the Middle East from 2019-2024, which will add 5.5 million t/a of sulphur production capacity, including additional LNG processing in Qatar via the Barzan project, more output from Iran's South Pars gas field, and refineries and gas plants in Saudi Arabia, as well as additional sour gas production in the UAE. All told, Middle Eastern sulphur production may reach 22.5 million t/a by 2024, representing over 40% of growth in sulphur output over that period. ■

CONTENTS

SULPHUR
ISSUE 387
MARCH-APRIL 2020
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North American sulphur

Above: Refineries on the Houston Ship Channel.

Although North America is no longer the world's largest sulphur exporter, it remains a major producer and consumer, and there are still significant exports and imports of sulphur into and out of the region.

Arguably the modern sulphur industry began in North America, via Frasch mining in the United States, and then recovered sulphur from sour gas in Canada and later refineries in both countries. While the US was always the largest producer, Canada became the largest exporter, much of it to the US, as the US used more domestically for phosphate extraction and other industrial uses. In its heyday North America represented the majority of global traded sulphur, with Canada representing 40% of the global total. The US alone produced 60% of the world's elemental sulphur in the 1950s.

The Frasch mines finally closed during the 1990s as more sulphur was coming from recovered sulphur at refineries and sour gas processing plants, but sour gas output has likewise declined this century as gas fields – some of them dating back to the 1950s – gradually became depleted, and the increasing abundance of sweeter shale gas this century has undermined the economic case for sour gas production. Canada was overtaken as the world's largest sulphur exporter in 2016 in the wake of the start-up of the huge Shah project in Abu Dhabi. However, the US is still the world's largest elemental sulphur producer and its second largest consumer (after China), and North America remains one of the mainstays of the world sulphur industry.

Sulphur production

In terms of elemental sulphur, there are broadly three sources of elemental sulphur in North America. Refining is the largest element, mainly in the United States, although there are also some refineries in the east of Canada which generate sulphur. Next comes sour gas processing mainly in the provinces of Alberta and British Columbia in Western Canada. Finally, Alberta also has significant sulphur production from processing and upgrading of oil sands bitumen.

Refining

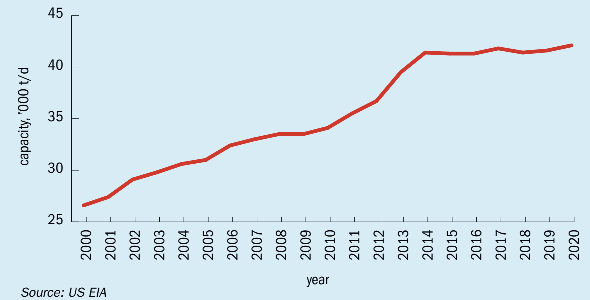
The refining industry is the main source of elemental sulphur in North America. The US is the dominant producer here, recovering 9.0 million tonnes of sulphur via refining in 2018. US domestic oil production had previously peaked in the early

Table 1: **Average sulphur content of inputs to US refineries**

Year	Sulphur content, % w/w
1985	0.91
1990	1.10
1995	1.13
2000	1.34
2005	1.42
2010	1.39
2015	1.45
2019	1.40

Source: US EIA

Fig. 1: **US refinery sulphur capacity, 2000-2020**



Source: US EIA

1970s at around 10 million bbl/d, and had been in a slow and steady decline into the early 2000s, when it had dropped to around half of its peak value at 5 million bbl/d in 2005. However, the revolution in extraction that hydraulic fracturing ('fracking') had given to the natural gas industry began to spread into oil extraction at that time, opening up many 'tight' oil fields that had previously been uneconomic to exploit. Tight oil production surged, and by the end of 2019, US oil production was at a record 12.2 million bbl/d and the country was a net oil exporter again for the first time since the 1940s, to the tune of a net 100,000 bbl/d.

The boom in domestic oil production has had a knock-on impact on downstream refining, but the picture is more complicated here. The net import/export figure above masks the fact that the US is both a huge importer and exporter of crude oil. Indeed, on average in 2018 the US imported 7.7 million bbl/d of crude oil and exported 7.6 million bbl/d, according to Energy Information Administration (EIA) figures. The reason for this is that tight oil and the natural gas liquids produced from gas fracking tend to be fairly sweet, whereas many US refineries, especially on the Gulf Coast, were geared up to handle sourer foreign imported crude, from Canada or the Middle East. In 2018, the US imported 3.7 million bbl/d of Canadian crude or synthetic crude, as well as volumes of 500-800,000 bbl/d from Iraq, Saudi Arabia, Venezuela and Mexico respectively, most of it heavy and sour, and generating significant tonnages of sulphur. Indeed, US refinery sulphur capacity has been rising over the past two decades to cope with both tightening fuel standards and a rise in the average sulphur content of crude inputs to US refineries. The latter can be seen in Table 1, as US refineries gradually processed sourer and sourer crudes on average – sulphur content of inputs to US refineries rose by 50% from 1985 to 2000, to take advantage of the price spread between more expensive and sought-after light sweet crudes as against cheaper, heavy, sour crudes. Recently, however, the tight oil boom has led to more low sulphur domestic crude being used domestically, and so for the past few years the average sulphur input figure has been falling. This has been exacerbated by the recent change in International Maritime Organisation regulations on the permissible sulphur content of bunker fuels. In order to produce sufficient low sulphur fuel oil (LSFO) and marine gasoil (MGO), refineries have been using lower sulphur inputs. This led to a significant drop in US refinery sulphur output in 2019, to 8.2 million t/a from a previous year's figure of 9.0 million t/a, and this may become the 'new normal' for at least a few years, until the global supply low LSFO and MGO evens out and more ships install scrubbing equipment allowing them to handle HSFO.

US refinery sulphur output is concentrated in the Gulf Coast region (PADD 3), where 60% of sulphur recovery capacity is located. PADD 2 is next, with 20% of capacity, and PADD 5 with 14%. The other two regions each have only about 2.5% each.

North of the border, Canada is the world's sixth largest oil producer, at 5.2 million barrels per day in 2018, representing 5.5 % of global oil production, and its reserves, if the oil sands patch is included, are the third largest in the world at 170 billion barrels, accounting for 10% of the world's oil reserves. However, Canada's refining capacity is relatively small; there are 16 refineries operational in Canada (including two bitumen refineries), with a total capacity of 2.0 million barrels per day. This is because more than half of Canada's oil production is exported, mostly to the US.

Refinery capacity is concentrated in the east of the country, especially Ontario, where there is a cluster near the US border, Quebec and the Atlantic coast (Labrador, Newfoundland, New Brunswick). These provinces between them operate 1.17 million bbl/d of capacity, or about two thirds of the total, 390 million bbl/d of this in Ontario. There are some small refineries in Saskatchewan and British Columbia, and most of the refinery capacity in Alberta is geared at processing oil sands crude. Outside of the oil sands patch, described below, 'conventional' oil refining in Canada produces about 600,000 t/a of sulphur, most of it in Ontario and Quebec.

Sour gas

North American sour gas production is mainly concentrated in western Canada, in particular the Western Canadian Sedimentary Basin (WCSB), which extends from Saskatchewan across northern Alberta and British Columbia and up into the Northwest Territories. Sour gas exploitation was pioneered in Western Canada, and sulphur production began at Jumping Pound in 1951. Gas production in Alberta peaked in 2001, and during the 21st century Canada's sour gas production has declined as fields matured and new fields were not tapped due to the rapid expansion of shale

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gas production south of the border in the USA. Gas prices fell from over $10.00/MMBtu to below $3.00/MMBtu, undercutting Canadian sour gas production. However, Canadian sour gas production now appears to have halted its long-term decline and stabilised at a steady, albeit lower level.

Even so, a symptom of the decline in Canada's sour gas production was Shell's sale last year of its Foothills sour gas assets, including the major Waterton, Jumping Pound and Caroline plants, to Pieridae Energy. Shell's plants produced 750,000 tonnes of sulphur in 2018; 300,000 t/a each at Caroline and Waterton, and 150,000 t/a at Jumping Pound. Other major producers included Tidewater at Ram River (186,000 t/a), AEC at Saddle Hills (130,000 t/a), Keyera's Strachan plant (28,000 tonnes) and Semcams at Kaybob South (114,000 t/a). These seven installations between them accounted for 1.2 million tonnes of sulphur, or about 75% of Alberta's sour gas sulphur output. Other Canadian sour gas production comes from neighbouring British Columbia, which produces about 250,000 t/a from sour gas.

US sour gas processing produced 627,000 tonnes of sulphur in 2018, according to the USGS. Most of this (75%) came from the PADD 4 and 5 region – the west coast and northern Rocky Mountains areas.

Of the remainder, almost all came from gas processing along the US Gulf Coast. US sour gas production continues to fall, for the same reasons as Canada, and the full year figure for 2019 is likely to be as low as 340,000 tonnes of sulphur.

Oil sands processing

A special case of refinery production is exploitation of Canadian oil sands bitumen. The mines are concentrated in northern Alberta. Very few refineries can process bitumen directly, so the bitumen is either upgraded to produce synthetic crude oil ('syncrude'), or diluted with lighter fractions such as naphtha to produce a 'dilbit' (dilute bitumen) or with syncrude to create a 'synbit'. These are light enough to be pumped, and so can be exported by pipeline or rail instead – around 60% of the oil sands production is exported in this way, much of it to be processed in the US. In 2019, Canada's oil industry produced about 1.9 million bbl/d of bitumen, and 1.1 million bbl/d of upgraded bitumen/syncrude, representing about 60% of Canadian oil production.

Oil sands typically contain about 4-5% sulphur by weight, and therefore upgrading or refining it recovers significant tonnages of sulphur. Alberta oil sands upgrading capacity has been slowly rising, generating 2.3 million t/a of sulphur in 2018. However, upgrading capacity has been expensive and hence the preference has been to export the dilbit/synbit where possible. But as Canadian oil production swings ever more towards oil sands-based production, so exporting has become complicated by lack of pipeline infrastructure to export it. As legal disputes continue over a variety of pipeline options to take dilbit west to the coast for export, south across the border into the US, or east to Canadian east cost refineries, cross-border rail traffic has increased, but for the moment all existing routes appear to be at or near capacity, and the Canadian government still has not managed to square the circle of generating export options for oil sands production. Lower oil prices also crimped some expansion plans for oil sands development, although production costs have been falling, especially for 'in situ' recovery, which represents 80% of new capacity. Nevertheless, it is the lack of pipeline export options which appear to have been behind the cancellation of Teck Resources 260,000 bbl/d Frontier project recently.

Expansion projects continue, but they are incremental. The Canadian Association of Petroleum Producers has reduced its estimates of increases in oil sands production, and now forecasts that output will increase by about 1.5 million bbl/d out to 2035 to a total of 4.2 million bbl/d.

Sulphur demand

The US phosphate industry has traditionally been the largest consumer of sulphur in North America, to make sulphuric acid for phosphate extraction. In the US, phosphate rock mining is concentrated in central Florida and Idaho, although there are also mines in North Carolina and Utah. US production of phosphate rock peaked in 1980 at 54.4 million metric t/a, and this had more than halved to 25.7 million t/a in 2018, as mines have become exhausted. Canadian phosphate mining finished in 2013 when Agrium closed the last operational mine at Kapuskasing, Ontario, after the reserves there were exhausted, and began instead importing phosphate rock from Morocco to supply its phosphate fertilizer plant at Redwater, Alberta.

Almost all (about 90%) of US demand for phosphate rock is for fertilizer production. The rest goes mainly to animal feed, and some phosphoric acid is used in the food industry. US fertilizer demand for phosphate is relatively mature, and for most of the 1990s and 2000s fluctuated between 3.8 million t/a P_2O_5 to 4.3 million t/a P_2O_5. Canada adds another 400-500,000 t/a P_2O_5 to this figure. However, there has been a pickup in demand in the past few years, due to increased plantings of maize and soybeans, which are more phosphate-hungry, as opposed to declining plantings of wheat, which uses less phosphate fertilizer.

North American production of phosphoric acid in 2018 was 12.8 million t/a in terms of tonnes product (6.9 million tonnes P_2O_5). Only 3% of this figure was represented by Canadian production, at Redwood, Alberta, with the remainder coming from the US. US downstream phosphate production is mainly aimed at mono- and diammonium phosphate, accounting for 2.5 million t/a P_2O_5 and 1.1 million t/a P_2O_5 respectively. North America's share of downstream phosphate production has steadily fallen since the mid-1990s. In 1995 North America claimed 45% of global phosphoric acid production, but the rise of China in particular and closures in North America has brought that share down to 15% in 2018 – still significant but not the dominant force it once was. Growth in production of cheap finished phosphates elsewhere in the world, such as Saudi Arabia and Morocco, are affecting the North American market, combined with depleting resources at phosphate mines. The fall has seen considerable industry rationalisation and consolidation, with only four producers now still active: Mosaic, Nutrien, Simplot and Itafos, and only nine phosphate processing sites now in operation.

There are still some new projects on the horizon; Arianne Phosphates is developing a phosphate mine and beneficiation complex at Lac a Paul in Quebec, Canada, commissioning is now set for 2021, according to Arianne. There is also a feasibility study underway on developing a 500,000 t/a phosphoric acid plant at Belledune in New Brunswick, using steam and fresh water from a nearby power plant and sulphuric acid from Glencore's Brunswick lead smelter to process 1.4 million t/a of the phosphate concentrate from the mine. Around 1.5 million t/a of sulphuric acid will be required, probably leading to imports of sulphuric acid to the side in addition to acid from the smelter.

Nevertheless, there is also an expectation that further capacity rationalisation may be ahead, and with it reduced demand for North American sulphur. The quantity of sulphur required to feed North American phosphate production has fallen from 11.3 million t/a in 1990 to 6.5 million t/a in 2016, and since then Mosaic has idled and then permanently closed its Plant City facility, removing another 550-600,000 t/a of sulphur demand from the market.

Outside of the phosphate industry, there is sulphur demand to manufacture sulphuric acid for metal leaching and other industrial processes, including caprolactam, pulp and paper processing, and especially sulphuric acid use as an alkylation agent in refining – a field in which the US refining industry has been a pioneer. These uses totalled about 2.8 million t/a of sulphur consumption in 2018.

Table 2: **North American sulphur production, 2019, million t/a**

	US	Canada	Total
Refining	7.9	0.6	8.5
Sour gas	0.3	1.7	2.0
Oil sands	(0)	2.5	2.5
Total	8.2	4.8	13.0

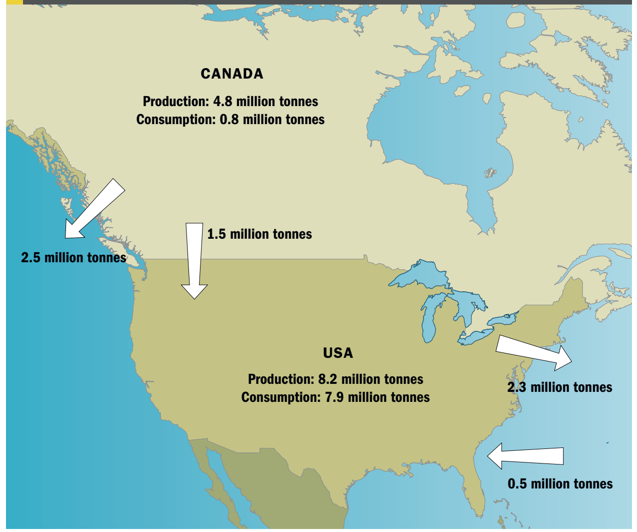
Sources: AER, CAPP, EIA, USGS

Sulphur markets

In total, US sulphur production was just over 9 million t/a in 2018, falling to 8.2 million t/a in 2019. As Table 2 shows, refining accounted for the vast majority of this. Canadian sulphur production was about 4.8 million t/a in 2019, with about 1.5 million t/a coming from sour gas processing in Alberta and 0.2 million t/a from sour gas processing in British Columbia. Another 2.5 million t/a came from oil sands upgrading, and 0.6 million t/a from conventional refining. This produced a total amount of elemental sulphur for North America of 13.0 million tonnes.

Canadian domestic consumption runs at about 0.8 million t/a, leading to a surplus of 4.0 million t/a, most of which is exported. In 2019, around 1.5 million t/a was exported south to the US, mainly as molten sulphur, while 2.5 million t/a was exported via Vancouver port.

Fig. 2: **Sulphur flows in North America, 2019**



The logistics of export from Canada can be complicated. The US market takes mainly molten sulphur for phosphate production, while overseas markets are generally based on dry bulk sulphur. As the US phosphate industry has shrunk over the past decade, so demand for Canadian sulphur has fallen. One of the issues is the long distances that sulphur must travel from Alberta to the US phosphate belt, most of it in Florida. This can mean that transport costs alone can already have reached $120/tonne before the cost of the sulphur itself is taken into account.

The other option is export through the port of Vancouver. This too can be a long distance, on average 1,400 km across the Rocky Mountains, with difficulties in winter caused by snowfalls and freezing temperatures. Another issue has been access to sulphur forming capacity for producers who have previously generally exported molten sulphur. In an effort to overcome this problem, the Heartland Sulphur project started up in late 2017. The facility, at Strathcona northeast of Edmonton, Alberta, can take large volumes of liquid sulphur and form them into up to 2,000 t/d (650,000 t/a) of wet prilled sulphur using the Devco process.

In spite of this, sulphur produced from the oil sands faces still more logistical difficulties in getting south, and as a result, Canada has a huge stockpile of sulphur, which stood at 11.5 million tonnes at the end of 2019, almost all of it sited at Syncrude's production facilities near Fort MacMurray.

Overall, the rise of new low cost sulphur export capacity from places like Abu Dhabi and Qatar has meant that the logistics cost of getting Canadian sulphur to international markets may crimp opportunities for expanded oversea sales in the longer term. On the other hand, with sulphur markets forecast to tighten over the next couple of years, prices could still support Vancouver exports for the medium term.

As well as the 1.5 million t/a from Canada, the US also imports about 500,000 t/a of sulphur from elsewhere in the world. Some of this used to come from Mexico, but Mexican exports of sulphur dried up in 2017. The cost of deliveries of molten sulphur by rail from Canada has prompted Mosaic to invest in a 1 million t/a sulphur melter at its New Wales site, allowing it to import formed sulphur from potentially cheaper overseas sources to operate its phosphate operations.

The US also exports sulphur, mainly from the Gulf Coast refineries. In 2019, this was a total of 2.3 million tonnes, for a net export figure of 300,000 tonnes, meaning that US apparent consumption of sulphur was 7.9 million t/a in 2019.

SULPHUR
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TSI Sulphur World Symposium 2020

PHOTO: RUDY BALASKO/SHUTTERSTOCK.COM

The Sulphur Institute is holding its annual meeting in Chicago, Illinois this year from April 20th-22nd.

The Sulphur Institute has selected Chicago, Illinois, USA, as the location for its Sulphur World Symposium 2020. Sited along the shores of scenic Lake Michigan, this world class city is the heart of America's Midwest and the second most visited city in the country with 58 million visitors each year. Iconic landmarks include the Art Institute of Chicago, the Willis (Sears) tower and the famous Magnificent Mile.

The following are abstracts of some of the featured presentations and speakers.

Symposium Schedule 2020

Monday April 20, 2020

08:30 - 11:00	TSI Annual General Meeting, Sullivan Room: TSI Members Only
17:00 - 18:30	Welcome Reception

Tuesday April 21, 2020

09:00 - 10:30	Speaker Session 1
10:30 - 11:00	Coffee Break
11:00 - 12:30	Speaker Session 2
12:30 - 13:30	Lunch
18:40 - 21:40	Evening Reception: a night at the Cubs' game

Wednesday April 22, 2020

09:00 - 10:30	Speaker Session 3
10:30 - 11:00	Coffee Break
11:00 - 12:00	Speaker Session 4
12:00 - 13:00	Lunch

What is next for sulphur and sulphuric acid markets after the swing to oversupply?

Peter Harrisson, CRU

Both sulphur and sulphuric acid markets moved into oversupply during 2019 with a weakened demand environment being the primary trigger. Weakness in consumption was evident in both fertilizer and industrial markets the softer fundamental hitting demand in almost all major sulphur markets. From 2020, the outlook is more of a supply growth story with increased sulphur supply from project commissioning and IMO 2020 upgrades. Acid markets are more focused on the growing influence of the Chinese smelting sector in international acid trade.

The progress of projects for sulphur and acid supply will be discussed. Despite the upturn in supply there remain opportunities for demand to return to growth with a focus in new capacity in fertilizer and metals sectors. The potential for new phosphate fertilizer capacity additions exist around the world, but which are best positioned to make it into production. Nickel, copper and lithium based demand continue to offer high growth potential but when and where will the market grow.

This presentation will review the current market and highlight the factors determining whether the market can find a path out of the current demand deficit and examine if there is a likely shift to a long term supply surplus.

China's role in the global sulphur and sulphuric acid industries

Freda Gordon, Acuity Commodities

It is no longer an exaggeration to say "when China sneezes, the world catches a cold." China's outstanding economic growth has helped it in becoming an emerging global superpower. One testimony to its power is when the trade war between the US and China escalated in 2019, many economists downgraded their views on global economic growth. In terms of sulphur and sulphuric acid, China is one of the most influential markets in the world. As its population and purchasing power grows, its agriculture sector has also been expanding, complemented by the rising capacities of Chinese phosphate fertilizer production. This supported China's imports of 11.7 million t/a of sulphur in 2019 and placed it on top of the world sulphur import league. The country has also transitioned from being a net importer of sulphuric acid to a net exporter as more smelting capacity comes on stream. Having exported 2.2 million t/a of sulphuric acid in 2019, its export volume is right behind the world's biggest export countries – Japan and South Korea.

This presentation will review China's principal import and export trade flows. It will also look into three main features that make China a unique market and have helped it in becoming a force to be reckoned with in the sulphur and sulphuric acid markets.

- Long-term planning/centralised power. With centralised power, China is able to work on long-range planning that helps the development of many industries, including the agriculture sector. One example that is relevant to agriculture as well as the sulphur and sulphuric acid markets is how China has been working on improving the environmental quality of its water, air, and land in favour of rapid economic growth over the past years.
- A huge market, more open than ever. China's size has helped it in becoming the world's biggest sulphur import market, and now a major sulphuric acid exporter. A huge market size also encourages the emergence of many tools in trading, including the Huaxicun paper market, of which we will discuss its influence on the global sulphur market.
- A large number of state-owned companies that compete with each other. State-owned companies have easy access to loans, and this is just one of the reasons certain industries in China are able to grow so rapidly. Several state-owned smelters, for example, are still able to run and export acid despite when export values have fallen to below zero.

Understanding sulphur's full potential – an integrated marketers perspective

Charles Ingoldsby, Shell Sulphur Solutions

For many Sulphur producers, Sulphur is merely a by-product of oil and gas production, something to be evacuated and ultimately exposed to a volatile commodities market. As a business dedicated to maximizing the end to end value of Sulphur, Shell Sulphur Solutions brings a different perspective to the Sulphur story. As one of the worlds few fully integrated Sulphur marketers, Shell has cultivated strong relationships across the Sulphur value chain and particularly in the fertilizer sector.

This presentation will help to illuminate the difference in value between Sulphur as a commodity and Sulphur as a plant nutrient. Review the history of SOulphur fertilization, understand the benefits of different Sulphur sources, and explore what the needs of the future might look like. Finally we will explore some of the options available to Sulphur producers looking to capture additional value from their Sulphur supply, among them, Shell's Thiogro technologies.

Participants will ultimately leave with an understanding that Sulphur is much more than a commodity; it is integral to our daily lives and will play a crucial role in attaining global food security sustainability.

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

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SulGas 2020

Dr Upasana Manimegalai Sridhar of 310i Technologies LLP introduces the round table panel. From left to right: Ritesh Gulabani (Dow Chemical International (P) Ltd), Rajesh Nandanwar (Bharat Oman Refineries Ltd), Manu Shreshtha Miglani (Engineers India Ltd), Rajiv Srinivasan (Shell) and Srinivas Vadlamani (Schlumberger).

Now in its second year, SulGas 2020, South Asia's only conference on gas treating and sulphur recovery, took place 3-4 February 2020 at the Novotel – Juhu Beach, in Juhu, Mumbai, India.

Building on the success of the first SulGas conference in 2019, this year SulGas attracted 170 delegates from 68 companies – 46 Indian companies, including 11 operating companies, and 22 international companies.

With IMO 2020 and BS-VI standards set to be in place in 2020, SulGas provides a technical forum for the sulphur and gas treating industry in the Indian subcontinent to convene and focus on understanding the problems and challenges facing the industry and to find solutions. With the processing of higher sulphur crudes and the changeover from BS-IV to BS-VI standards across all refineries in India, and the similar tightening of standards in the rest of the Southeast Asia region, the region is looking for the best way to remove, store and sell more sulphur.

The speakers at this two day event, which is organised by Three Ten Initiatives Technologies LLP, came from a variety of operating, licensing, engineering, and technology companies. SulGas focuses on issues unique to the region in the areas of:

- Equipment and process design;
- Process optimisation;
- Near misses;
- Analytical methods;
- Failures and successes of troubleshooting efforts;
- Plant operations.

The conference started off with an Experts' Forum. **Nate Hatcher** of Optimized Gas Treating and **Manu Miglani** of Engineers India Limited provided design guidelines for heat stable salts (HSS) levels in amine systems. They discussed work undertaken to clear up a number of misconceptions that have been widespread for many years concerning HSS. Most of these misconceptions result from differing definitions, poor understanding of chemistry and the misuse of jargon. The effects of HSS on treating performance, operations and corrosion were reviewed with several quantitative case studies and corrosion measurements. With this understanding, previous design guidelines can be better understood and placed in context to their areas of applicability. For a given application, there will be a "sweet spot" in the treating, which can only be revealed through process modelling with a truly fundamental rate-based model that uses the correct chemistry.

The next presentation in this session was by **Ritesh Gulabani** of Dow Chemical International (P) Ltd who discussed key points for the design and operation of low-pressure amine plants, e.g. tail gas treating units (TGTU) for sulphur recovery units, acid gas enrichment (AGE) for sulphur plant feed quality improvement and CO_2 capture (CCU) from exhaust gases. Specific treating objectives, commonly employed solvents, feed gas composition, absorber operating pressure and limiting factors, typical treated gas specifications and solvent regeneration requirements for TGTU, AGE and CCU plants were discussed.

Technical programme

The technical agenda included sessions on:

- SRU optimisation and control;
- Systems and simulation;
- Gas and liquid treating applications;
- Case studies – learnings and experiences shared;
- SRU reliability enhancements;
- Innovation in design and equipment;
- Separation technology.

In addition, a round table session was held on day 2 with a panel of senior experts from the SulGas advisory committee responding to questions arising throughout the conference and discussing design, operating, and other practical issues of concern in the Indian context.

SULPHUR
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Better monitoring and control in Claus plants

Applied Analytics discusses potential improvements made possible with data and analytical measurements fed into improved mathematical models to produce a more proactive approach to control and better performance of sulphur recovery units, AMETEK Process Instruments explains the benefits of feed forward control, SICK reports on reliable continuous emission monitoring systems and WIKA introduces a new purge-free system to measure refractory temperature in the Claus reaction furnace.

The control of a sulphur recovery Claus plant has been based on using simple concentration feedback for air demand control for the better part of the past 70 years. While the original British patent was issued in 1883, the Claus process was not implemented on a large scale until approximately 100 years ago and was using simple photometers since the 1960s to make measurements.

The importance of a sulphur recovery system has become an essential engineering control parameter in the modern world and more than likely will be progressed and expanded upon in the future. The continuing discovery and expansion of geologically abundant resources has led to the processing of a larger quantity of natural gas and crude oil of varying quality that potentially contains higher sulphur content. Sulphur recovery must be utilised to remove dangerous and toxic hydrogen sulphide (H_2S) and to limit sulphur emissions, primarily sulphur dioxide (SO_2).

Improvements in monitoring equipment and process control sensors over time have resulted in increased efficiency and lower maintenance in sulphur recovery units (SRUs) versus their original process controls. Analysers were developed for properly determining the compositions of the feed gases and the acid gas inlet for H_2S content and impurities as well as instrumentation for temperature and pressure measurements prior to the reaction furnace burner. Analysers that monitor the Claus catalytic outlets for controlling the oxygen combustion air for maintaining the appropriate stoichiometric equilibrium in maximising sulphur recovery efficiency were also introduced. Improvements were made with flow equipment for monitoring reaction furnace residence time and sensors for catalytic converter bed temperatures and process reheating between stages. Monitoring of sulphur tail gas composition to tail gas clean-up units and subsequently monitoring the final emission outputs of the stack was implemented. With the introduction and implementation of better process instrumentation over time, sulphur recovery units now have better control, higher recovery efficiency, improved safety, reduced maintenance, and smoother plant start-up and shutdown. Even with the availability of all of these improvements in process instrumentation, operating and maintaining an efficient sulphur recovery unit is still a challenging task from a process control standpoint due to the complexity and magnitude of all the interlinked variables throughout process production.

Optimising a Claus plant

The combustion air feed rate is the most critical variable that affects the efficiency of a Claus plant. The combustion portion of any sulphur recovery unit is designed to produce enough SO_2 from equation 1 to meet the required ratio from equation 2 of 2 moles of H_2S to every 1 mole of SO_2 in the later catalytic and finishing sections.

$$H_2S + 1.5\,O_2 \rightarrow SO_2 + H_2O \qquad (1)$$

$$2H_2S + SO_2 \rightarrow 3S + 2H_2O \qquad (2)$$

Commonly, the air that supplies oxygen to the furnace in the Claus process is controlled by two valves in parallel, a main valve, and a trim valve. Ideally the trim valve is controlled using a tail gas analyser (H_2S, SO_2) that is installed after the final reactor stage and before the incinerator, and the main valve is controlled using a feed forward basis that combines an H_2S analyser and acid gas flow rate. The tail gas analyser provides the ratio from equation 2 by measuring the H_2S and SO_2, which is used to control the trim valve.

Often plants forgo the feed forward analyser and rely on the tail gas analyser to control the air demand.

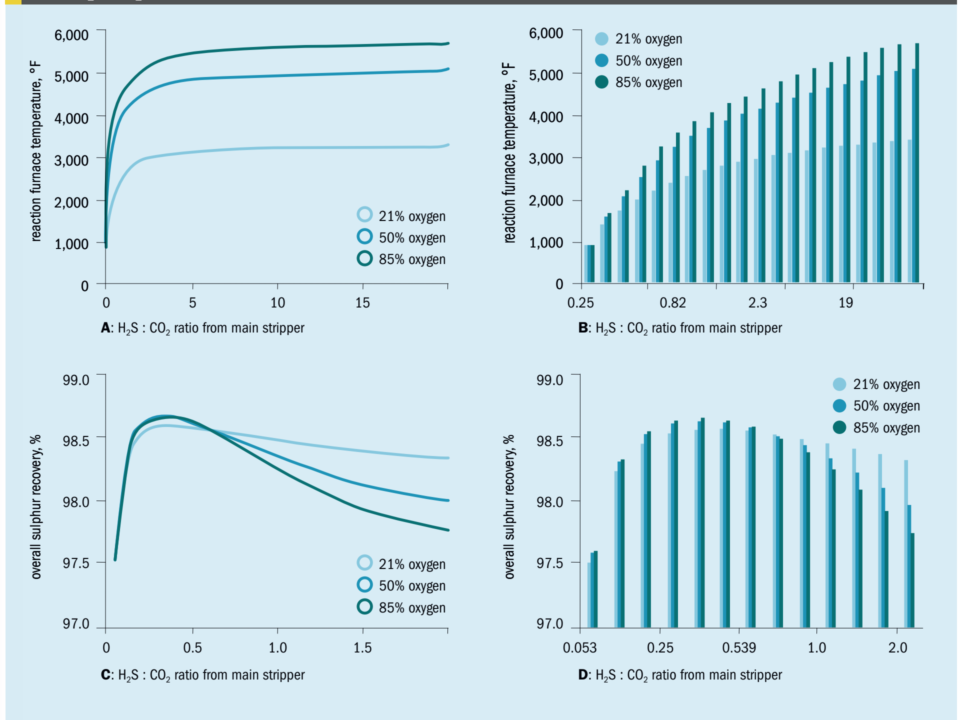
There are issues with this approach related to the dead time between tail gas readings and air introduction can be significant. Process modelling along with a feed forward analyser can help with this dead time issue.

Carbon dioxide in the feed gas can also influence the efficiency of a Claus plant. High carbon dioxide levels can result in a severe drop in combustion chamber temperature. The higher the H_2S/CO_2 ratio, the higher the combustion chamber temperature will be.

However, this does not correlate directly to an increase in efficiency. The relationship between H_2S/CO_2 ratio and efficiency of sulphur recovery is depicted with a concave down (hill shape) graph (see Fig. 1) that has a maximum or ideal H_2S/CO_2 ratio.

The ratio is typically controlled during the design phase by adding an acid gas enrichment process that selectively removes H_2S from the CO_2 heavy stream, and then this upgraded gas is sent to the sulphur recovery unit. However, as mentioned earlier swings in the ratio have an effect on the temperature in the furnace and the ratio should be monitored at the inlet of the Claus plant to take pre-emptive actions to properly set the furnace temperature according to the incoming gas mixture.

Fig. 1: H_2S/CO_2 ratio curves



Lean of peak, rich of peak

The H_2S/SO_2 ratio in a typical Claus unit should be controlled as closely as possible to 2:1. However, there are instances that require different ratios, which come about in more complex Claus unit configurations. The first example would be when the sulphur recovery unit has a tail gas treatment unit. The tail gas treatment unit is affected by SO_2 and precautions are taken to ensure that this component is not present after the catalytic stages of the sulphur recovery units. If there is even 12-12.3% excess air the tail gas treatment unit can completely fail. The pH of the system drops dramatically and the excess hydrogen can drop to zero. When a tail gas treatment unit is used in the plant design, the air demand is run on the lean side, which chokes the SO_2 production and keeps a 4-5:1 ratio of H_2S/SO_2. A second example of running off peak is for SUPERCLAUS units. SUPERCLAUS units operate using the absolute value of H_2S as a point of control instead of the 2:1 ratio.

Efficiency improvement by feed forward control

SRU plants often process gas of unknown and fluctuating compositions coming from a variety of process units in a refinery. Feed forward control is key to handling these fluctuations.

One of the difficulties process analyser manufacturers face is the measurement of unknown process gas compositions. The other challenge is that the measurement must be very fast. The process gas needs to be measured right at the inlet of the Claus reaction furnace. The reaction time of the process gas in this reaction chamber is around three seconds, so any measurement taking longer becomes useless. In addition, ensuring the safety of refinery operating personnel is of paramount importance as the gases being measured can potentially contain up to 90% hydrogen sulphide (H_2S), one of the most toxic gases in a refinery. Having a simple, easy to understand and operate sampling system eliminates human errors and improves safety.

AMETEK Process Instruments has introduced a measuring system which meets these challenges, providing fast, reliable and safe measurement of process gas streams with unknown composition. End user feedback has confirmed its value with several users of this feed forward analyser reporting, "We decided to install this analyser in order to mitigate upsets of our SRU plant, in the beginning we were looking at the appearance of upsets, but now we have found the instrument is also useful for showing the disappearance of the upset condition as well".

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Process upsets

The TGTU operation of a sulphur plant depends on a smooth operating Modified Claus unit, but unless the SRU is handling a stable acid gas, e.g. in a small scale natural gas treatment plant, this is often not the case.

Unusual process conditions (upsets) are never welcome and shouldn't be considered as "normal" but in daily life they happen, particularly when processing different acid gas streams or sour water stripper gas in the SRU. What is important is how well the situation can be controlled.

In some cases an upset may cause loss of recovery efficiency, resulting in higher emissions, which is undesirable but manageable, but in other cases, in addition to increased emissions, there may also be damage to process units. The latter can be caused by the breakthrough of hydrocarbons. Table 1 illustrates the impact of hydrocarbons on the air demand.

Table 1: **Impact of hydrocarbons on air demand**

Compound	Moles O_2 per mole HC	Ratio of O_2 needed per mole HC compared to mole of H_2S
Methane	2	4
Ethane	3.5	7
Propane	5	10
Butane	6.5	13
Pentane	8	16
Hexane	9.5	19

Source: AMETEK

The higher oxygen consumption from the hydrocarbons will result in an air deficiency, which will be measured by the tail gas analyser and fed back to the process control system but only after a time delay (process lag time). Furthermore, the tail gas analyser only controls the trim air to the Claus reactor. If this is not enough, knowing about the condition of the upset will help.

Unfortunately, an accurate and component specific measurement is not possible in the required time. These measurements are only possible with the use of process gas chromatographs which take around 5+ minutes from the change of the process gas to any result of measurement (this includes sampling system). The upset may also be over before it is reported.

In the worst case scenario, hydrocarbon breakthrough, i.e. when there is insufficient air to burn the hydrocarbons, may lead to soot formation in the first catalytic reactor. Other consequences include loss of recovery efficiency leading to higher sulphur emissions.

The TGTU will be forgiving and correct for the appearance of hydrocarbons. As an increase of hydrocarbons in the feed gas will lead to an air deficiency, the H_2S concentration in the tail gas will increase. However hydrocarbons can disappear as fast as they appear. The control system may have just managed to adjust the air flow to the reaction furnace so that everything is back to the required control set points but if the hydrocarbons then suddenly disappear there will be too much air fed to the reactor which will increase the SO_2 concentration in the tail gas to unacceptable levels. The important question now is whether there is enough hydrogen available to hydrolyse all of the SO_2 into H_2S. The following CoMo catalysed reactions take place in the reducing reactor:

$$SO_2 + 3H_2 \rightarrow H_2S + 2H_2O \quad (3)$$

$$S + H_2 \rightarrow H_2S \quad (4)$$

$$H_2O + CO \rightarrow H_2 + CO_2 \quad (5)$$

$$COS + H_2O \rightarrow CO_2 + H_2S \quad (6)$$

$$CS_2 + 2H_2O \rightarrow CO_2 + 2H_2S \quad (7)$$

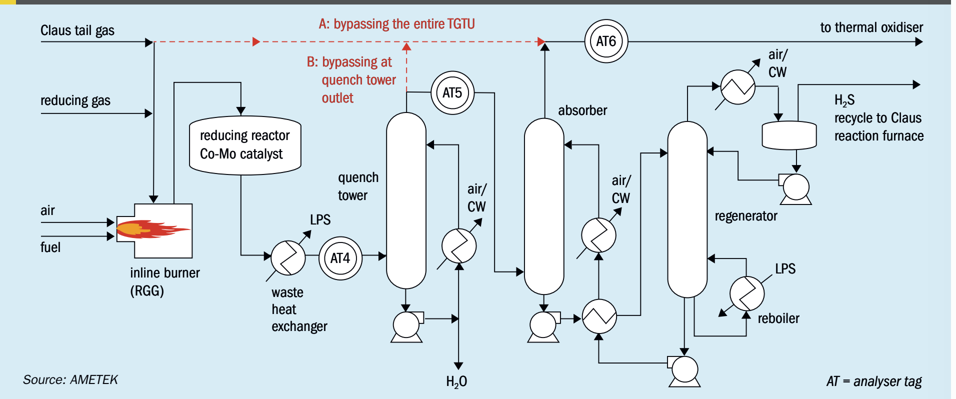
Any SO_2 breakthrough into the absorber tower will cause irreversible damage to the amine, which can be quite costly (costs of $40-50 per litre are not uncommon for specific amines). In this scenario, bypassing the absorber is the only option. There are two bypass options:

- bypassing the entire TGTU
- bypassing at quench tower outlet

Both options are illustrated in Fig. 2.

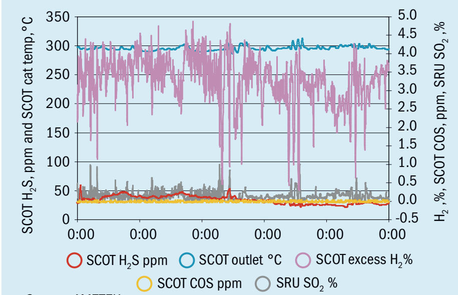
Process gas analysers (AT4, AT5 and AT6) can help to mitigate the worst case scenarios of 1) damage to the absorber amine and 2) bypassing the TGTU for an extended period of time.

Fig. 2: **Bypass options in the tail gas treatment process**



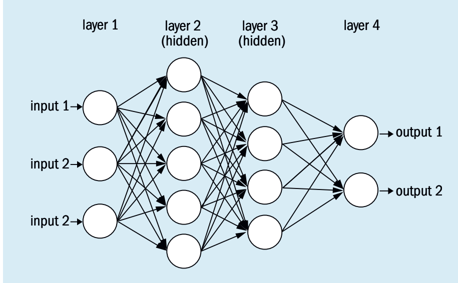
Source: AMETEK — *AT = analyser tag*

Fig. 3: **Example of SO_2 breakthrough**



Source: AMETEK

Fig. 4: **Neural network**



Source: Applied Analytics

In some plant setups both measurement options are utilised in the TGTU. AT4 monitors SO_2 concentrations, to prevent damage to the amine found in the absorber. AT5 measures the H_2S concentration entering the absorber, to quantify the amine load required. AT6 measures the H_2S (and potentially COS and or CS_2) concentration to assist in isolating operational problems and quantify contributions to sulphur emissions.

Recall that the reduction reactor in the TGTU converts all remaining sulphur components carried over from the modified Claus to H_2S, which is removed by the absorber and recycled to the Claus reaction furnace. In order for these reactions to take place, a reliable supply of hydrogen is required.

The graph in Fig. 3 shows the H_2 reading as a function of an SO_2 excursion. As soon as there is a deficiency of H_2, SO_2 breakthrough becomes likely. Looking more closely at the reactions taking place in the reducing reactor (equations 3-7) it can be seen that every mole of sulphur also consumes one mole of hydrogen. As such, presence of SO_2 at AT4 indicates that the hydrogen feed should be increased. Some users will monitor hydrogen at this point (or at AT5 or AT6), to identify whether or not too much hydrogen is being injected.

Proper selection, installation and operation of process analysers can reduce emissions, safety risks and operational costs in SRUs.

SRUs have historically been complex to operate because of the varying make-up of the feed gas streams and the multiple thermal and chemical processes used to remove elemental sulphur, but AMETEK analytic solutions continue to reduce that.

Artificial intelligence – a proactive approach to control

Applied Analytics is looking into adding more measurements upstream of the thermal reaction furnace (i.e. H_2S/CO_2 in acid gas, H_2S in amine, H_2S in sour gas inlet) and incorporating those measurements along with other plant specific data into robust mathematical models to yield a more efficient and predicable sulphur recovery unit.

The basis behind the artificial intelligence (AI) in a plant is that the system would take in a series of inputs (in this case this would be the process data at all the different analyser and instrument points) through an adaptive program to learn and optimise the process. AI uses what is called a neural network (Fig. 4) which is a computational approximation of how the mind works. The neural network is built through the interaction of nodes. The data comes in and is run into the first layer, layer 1. The data gets combined into a series of nodes in hidden layers shown below as layers 2 and 3. Each of the nodes in the hidden layers performs a function with the data and then passes the new data forward. Once the information is translated through the hidden layers the data is compiled again into an output. In this case the outputs would be adjusted set points for the system. There can be a multitude of hidden layers depending on the required results. Using learning algorithms allows for the system itself to adapt based on the results, changing the parameters of the nodes as the system is running to optimise performance. As can be seen by the setup in Fig. 4 even with as few as three inputs the system is making a vast number of connections between the data and building out correlations based on this. A system built like this would be tuned to the specific process and the system would be able to adapt to the changes in that system.

Using this technology would allow the creators of the AI to build in certain parameters in which the AI would be able to run, ensuring that the process changes were not overcompensated for during the onset period while the system is learning or by erroneous reading. This could also force the system into only running in known safe run areas for the sulphur recovery unit. Using all the data that the system collects the AI could act as both a control unit for running the plant and it could also create an overview of how the plant is functioning, detecting issues long before they become problems. This has the potential of both giving invaluable information on how the plant is running and maintenance that needs to be done before it affects the product of the system or the run time.

The recent push for sulphur recovery plants to release less sulphur and the regulations that are being put in place make sulphur recovery a prime candidate for AI modifications. Many of the factors in the Claus plant affect the efficiency of the sulphur recovery unit. The main factor as mentioned above is the H_2S and SO_2 ratio.

This ratio is most generally determined by the ratio of oxygen to the acid gas that is allowed into the reaction chamber, however there are many other factors that affect this reaction. Side products are often formed in the reaction chamber and beyond creating unwanted products their presence can alter the expected stoichiometry of the reaction and that of the downstream reactions. Additional hydrocarbons or CO_2 in the feed can upset the burn temperature leading to more side reactions or react with and use up the oxygen meant for converting the H_2S to SO_2. These reactions are dependent on the tem-

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ISSUE 387
MARCH-APRIL 2020

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peratures in the chamber, fluid dynamics (mixing), heat transfer, along with the composition of the feed streams at the entrance to the reaction chamber.

Current modelling software is not able to perfectly predict the outcome of this reaction as there are many reactions that are taking place. Most models focus on just the few reactions below or fewer, however some of the more comprehensive models can have thousands of assumed reactions happening in the chamber. Modelling these though a kinetic model has shown to be the most closely correlated to the actual results seen in the plant. Even this is not a perfect simulation and has its inaccuracies, particularly around some of the side reactions. Additionally, the process is not always constant and can change based on a variety of factors like the feed composition into the reaction chamber and the mixing of the air and acid gas. Since each feed stream is different and the plants are not designed identically there has yet to be a model created that can fully describe every process and predict the outcomes and changes during the systems run time well enough to fully optimise the systems. Some adaptive kinetic models have shown promise on running sulphur recovery units in stabilising out the systems and reducing spikes in H_2S/SO_2 ratio. These systems are the first steps of AI implementation in sulphur plants.

Like much of chemical engineering, AI builds out models based on the data collected from process runs. This data is then compiled and the system uses this data to more tightly control the system. Feeding as much information to that AI as possible will allow it to make process adjustments to optimise the reactions in the plant based on how the specific plant itself is running. Instruments around the reaction chamber such as temperature, pressure, and flow analysers along with the compositional data from the acid gas analyser and the tail gas analyser will allow the AI to react quickly to changes seen. Adding analysers at the inlet of the process before the amine towers and on the rich and lean amine streams is always a good idea as it gives even more information allowing the user to predict how the system will react before the gas gets to the acid gas analyser. Adding these analysers to the AI inputs allows the AI to track how concentrations on the front end and the condition of the amine affect how the amine towers are working and adjust for the changing feed into the reaction chamber faster before it reaches the feed.

Commonly, the main (and sometimes only) analyser feedback used is the tail gas analyser. Since it is on the end of the process this analyser can have a 3-minute lag or more after the gas enters the system making the system reactive rather than proactive. If the tail gas analyser is coupled with feed forward analysers, the process becomes much more predictive. After adding these analysers, the AI takes all the data across the process, which can include the massive amount of data that is now stored by the DCS of trends over the past years and fills in the neural network based on the programmer's instructions. This network would be used to determine the best settings for the specific reactor in the specific plant incorporating the analyser response times and the process lag time between changes and when the process reacts. Process controls based on these parameters will be predictive and changes consider all the available information to keep the system running at peak performance.

In addition to the increased efficiency and performance, this would also allow for the operators to only do required maintenance when it is needed, as opposed to during manufacturer recommend maintenance schedules. Doing this decreases the amount of time and money invested into the process. Through this and the AI modelling all these systems allow for the process to run more efficiently adding value to the customer through the predictive analytics which decreases upsets and ensures the plant is running at peak performance.

Reliable CEM systems for sulphur recovery units

Monitoring the flue gases exiting the final stack of the SRU is a legislative requirement and places unique challenges on the continuous emission monitoring (CEM) system.

Emission limit values for compliance are stated as normalised concentrations, i.e. referenced to 1,013 mbar, 0°C, dry basis (0 vol-% water vapour) and typically normalised to a given oxygen concentration (3 vol-% O_2). Therefore, as well as the prescribed pollutants such as SO_2, NOx and CO, the emission monitoring system should additionally measure oxygen and unless measured dry basis, also water vapour.

Conventional cold dry extractive CEMS design

CEM systems for the purpose of measuring and reporting flue gas emissions behind a conventional combustion process have historically employed a cold extractive gas analyser. This CEMS design is based around pre-filtering an extracted sample gas to remove particles and then drying the gas by passing it through a refrigerating cooler (operating at 2-5°C) to condense out the water vapour, which is then removed. The dried sample gas flows via a sample pump to the non-dispersive infra-red (NDIR) gas analyser, which simultaneously measures SO_2, NO and CO by means of quantifying the amount of infra-red light absorbed at wavelengths specific to these different gases.

An additional paramagnetic oxygen detector module serves to allow the pollutant concentrations to be "normalised" to the oxygen concentration at which the pollutant emission limit values (ELV) are referred to. However, the particular sample gas properties found in the flue gas behind the SRU thermal oxidiser present significant difficulties when considering the application of this classical CEM system design.

First and foremost, the presence of elemental sulphur in the background gas is a major deterrent to utilising a sampling method which is based around chilling the sample gas to remove water. Cooling a sample gas containing elemental sulphur will result in solid and liquid sulphur blocking the sample system. Contamination in the sample cell can have fatal consequences.

Similar issues surround the cooling of any sample gas containing significant concentrations of sulphur trioxide (SO_3), which once below its acid dew point and if not removed with 100% efficiency can cause significant corrosion problems, especially to the sensitive, gold-coated gas analyser sample cell.

Finally, representative measurement of low SO_2 concentrations is compromised when the drying method creates water droplets, which prior to removal are in contact with the gaseous water-soluble SO_2 molecules.

For these combined reasons, the conventional cold, dry extractive gas analysis system is entirely unsuited to the application challenges of SRU continuous emission

PHOTO: SICK

Fig. 5: Optical window contaminated by sulphur.

CONTENTS
What's in issue 387
COVER FEATURE 1
Kuwait's sulphur boost
COVER FEATURE 2
Sulphur in North America
COVER FEATURE 3
Redox reborn
COVER FEATURE 4
Better control in Claus plants

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ISSUE 387
MARCH-APRIL 2020

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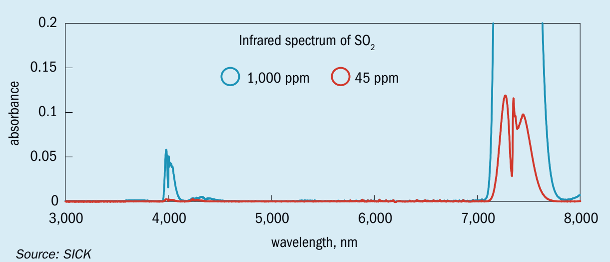
Fig. 6: **SO_2 wavelength selection with respect to target gas concentration**



Source: SICK

monitoring. Fig. 5 shows an optical window of a measuring cell fatally contaminated by elemental sulphur.

Hot wet extractive CEMS design

In recent years, the hot wet extractive analyser has been employed as the basis to continuously measure and report emissions behind the sulphur recovery unit. It has proven itself to be far better-suited in comparison to the conventional cold extractive analyser.

This analyser design is known as "hot wet extractive", because rather than cooling the extracted sample gas to remove water as a means to dry the sample gas, the sample gas is kept at a high temperature well above its dew point temperature and as such, the pollutant concentrations are measured in a "hot, wet" condition.

This design requires all elements of the gas analysis system, i.e. sample gas extraction probe, heated sample gas line and gas analyser to be thermostatically controlled at a temperature of 180-200°C. Since water vapour is not removed, it must be measured, both to dynamically correct for its cross-senstitive effect on other gases and secondly to enable pollutant concentrations to be expressed, dry basis.

The measurement principle is based on the absorption of infra-red light characteristic to pollutant species. The hot extractive gas analyser has a multi-component capability. A single hot extractive gas analyser can continuously measure SO_2, NO, NO_2, CO, H_2O, CO_2 and O_2. The oxygen measurement for normalisation purposes is achieved by integrating an extractive ZrO_2 sensor within the heated measuring section of the analyser.

The design principle of the analyser allows it to be configured to measure widely varying flue gas concentrations as a function of rapidly changing process conditions.

For steady state conditions, the primary SO_2 range might be 0-300 ppm. However, the analyser can be configured with a secondary SO_2 range, for example 0-8,500 ppm SO_2. This ensures that the analyser measures SO_2 with optimum uncertainty regardless of whether very low SO_2 concentrations are prevalent during typical steady-state conditions, or when several thousand ppms SO_2 are present during TGTU bypass. Fig. 6 shows the SO_2 wavelength selection with respect to target gas concentration.

A new version of the hot extractive analyser, MCS 200 HW, manufactured by SICK AG has recently been certified by testing authorities in both Germany (TUEV Rheinland) & UK (MCERTS) for the purpose of continuous emission monitoring according to European regulation EN 15267.

Purge-free refractory temperature measurement

In a Claus unit, it is important to measure the refractory temperature to make sure it does not exceed refractory limits. Thermocouple sensors and pyrometers are used to monitor the refractory temperature.

Type S thermocouples (see Fig. 7) are typically used since they basically show no aging up to temperatures of 1,400°C. They are also an excellent candidate because they can work well in a reducing or inert atmosphere. The downside of a Type S thermocouple is that it is susceptible to contamination and hydrogen will cause the wires to become brittle. Both phenomena will cause the thermocouple to fail.

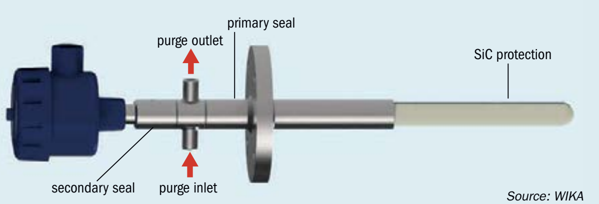
Until now, the basic solution to this was to purge the thermocouple. By doing a purge, the gases and hydrogen are swept away from the thermocouple itself. The problem with a purge is twofold:

- A purge is considered a high maintenance item. If you have a purge system you must monitor it to make sure the flow rate is correct and that all components are operating correctly. There is a cost to get the purge system installed and to have a constant use of gas, which should be nitrogen but is often air.
- The flow rate must be set properly. If it is too low or there is loss of purge, the thermocouple will become contaminated and break. If the purge is too high, the thermocouple reading will be lower, giving a false sense of comfort.

WIKA has a totally different method for reliable temperature measurement of refractory in Claus units that can be realised without the installation and challenge of maintaining a purge.

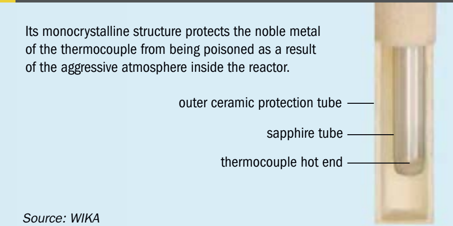
WIKA purchased a company that produced a system using a monocrystal sapphire (Fig. 8), which has been used in gasifiers in the GTL industry. Its monocrystalline structure protects the noble metal of the thermocouple from being poisoned as a result of the aggressive atmosphere inside the reactor. This solution has been used successfully in different reactors worldwide since 1997 under the designation model T-FZV. Pressure-tight, hermetically sealed junctions between the sapphire and metal protection tube, and also a multifold sealing system in the connection housing prevents toxic gases from

Fig. 7: **Protecting the Type S thermocouple**



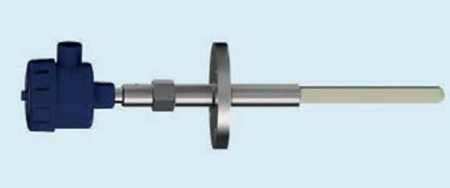
Source: WIKA

Fig. 8: **Monocrystal sapphire temperature measurement**



Source: WIKA

Fig. 9: **Sapphire design thermocouple**



Source: WIKA

being able to escape the reactor (Fig. 9).

This solution has also been installed and used in a couple of Claus units in Europe. The first one has been running for over six years and continues to operate today. The second one was installed almost three years ago and the customer reports that they will be installing the WIKA Sapphire solution (Fig. 9) on the other Claus unit during the next turnaround.

The key to this success is the monocrystalline sapphire, which can dramatically slow down hydrogen migration. There have been attempts to use just sapphire, but the crystalline structure allows for hydrogen to migrate. It is also important that the design of the unit remains sealed in case of breakage. There are things that can be done to minimise breakage due to refractory shift, but gas should not escape the system into the atmosphere.Another increasing concern nowadays is how to monitor if there is a catastrophic loss of the refractory. Wika is currently conducting research within its new state-of-the-art research furnace and reactor to test different methods, including fibre optics, magnet thermocouples, washer thermocouples, and other designs. ■

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CONTENTS

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Improved sulphur degassing

Fluor/GAA continue to strive to improve the performance of the D'GAASS out-of-pit liquid sulphur degassing technology based on commercial operating experience and ever-changing environmental emissions regulations. **T. Chow** and **S. Fenderson** of Fluor Energy & Chemicals/Goar, Allison & Associates discuss operating experience that has led to the improvements of the new patent-pending third generation D'GAASS3G technology.

All product sulphur from modified Claus process sulphur recovery units (SRUs) contains residual H_2S; some as dissolved H_2S and some in the form of loosely chemically bound polysulphides, H_2S_x. The total residual H_2S concentration is influenced by the H_2S vapour concentration (partial pressure) and the temperature at which the sulphur product condensed. As SRUs are pushed to and beyond their design capacities, the H_2S content of the product sulphur increases. Oxygen enrichment also results in higher residual H_2S. The average H_2S concentration in typical SRU product sulphur is 250-350 ppmw. Some H_2S is released during sulphur storage, handling, and transportation.

Several factors contribute to the release of H_2S from liquid product sulphur. Primary contributing factors to the release of H_2S from liquid sulphur are low H_2S concentration in the gas above the liquid sulphur, mechanical agitation, cooling, and time. The equilibrium ratio of H_2S to H_2S_x is dependent on temperature. The equilibrium ratio of H_2S/H_2S_x is about 1.5 at 155°C and 10 at 125°C. Over time, dissolved H_2S will desorb into the gas phase; physical desorption is favoured by low H_2S gas concentrations. As H_2S is desorbed, some H_2S_x is converted to H_2S to maintain the equilibrium H_2S/H_2S_x ratio. The conversion of H_2S_x to H_2S is relatively slow, and the overall H_2S release rate can be controlled by the rate H_2S_x is converted to H_2S.

The released H_2S results in potential safety hazards from the toxic H_2S gas and potentially explosive concentrations of H_2S in air. Formed solid sulphur product from undegassed sulphur is more friable (prone to fracture and create dust). The release of H_2S from liquid and solid sulphur results in noxious odours. Undegassed sulphur is more corrosive. Degasification of liquid sulphur controls most of the above listed problems.

Sulphur degassing

Sulphur has been degassed commercially since the 1980s, but continues to be more widely applied as the emphasis on minimising sulphur emissions and improving safety have become higher priority items. There are two major classifications of sulphur degassing processes:

- in-pit/tank atmospheric pressure processes;
- out-of-pit processes.

Out-of-pit processes have the advantage of being able to operate at pressures high enough to allow the H_2S containing effluent air to be directly routed to the SRU thermal stage or tail gas clean-up unit.

D'GAASS process history

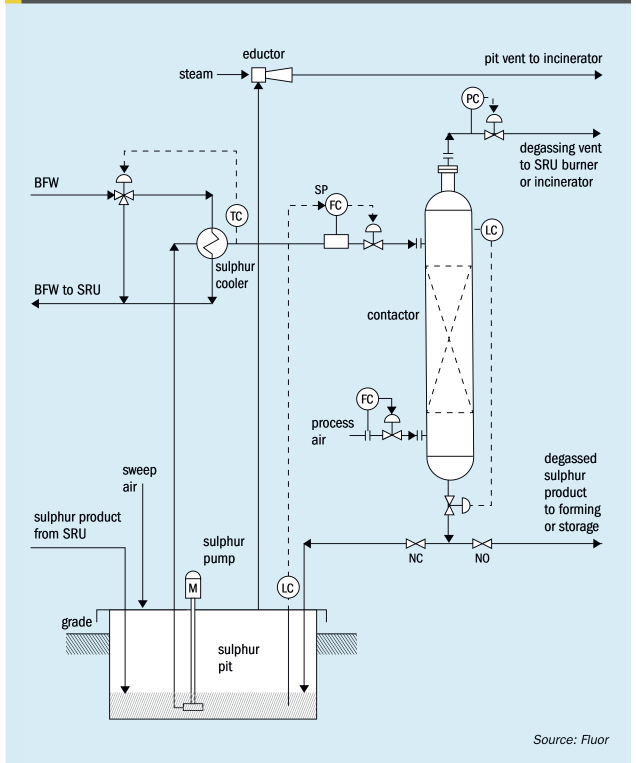
The D'GAASS process (Fig. 1) is an out-of-pit process that was introduced to the sulphur industry in 1997. The D'GAASS process was developed on the idea that degassing could be accomplished primarily through the oxidation reaction of H_2S and H_2S_x by oxygen dissolved in liquid sulphur. The oxidation reaction had been recognised as contributing to the overall degassing performance in the in-pit atmospheric pressure processes. The D'GAASS process operates at elevated pressure to increase the rate that oxygen dissolves in sulphur and increase the equilibrium concentration of oxygen in sulphur. This results in greatly reduced required degassing residence time (less than one hour). Sulphur is pumped from the sulphur rundown pit to the degassing contactor. Sulphur enters near the top of the contactor. Process air enters near the bottom of the degassing contactor. Sulphur and process air flow countercurrently across vapour liquid contacting internals through the contactor. The contactor vessel is sized to provide the required residence time based on the sulphur production rate, feed H_2S concentration, operating pressure, and process air feed rate.

Degassing residence time is maintained by controlling the level in the degassing contactor by regulating the rate degassed sulphur exits the bottom of the contactor; the operating pressure is controlled by regulating the overhead gas rate exiting the vessel. Operating under pressure allows the overhead gas routing to the SRU thermal stage, oxidation type tail gas clean-up units, or the plant incinerator. The degassed product sulphur flows to storage, forming, or loading without additional pumping.

Since the introduction and installation of the original units, several modifications/improvements have been incorporated into current D'GAASS unit designs. The original units operated at higher pressures than current design. Also, the original units utilised a bed of oxidation catalyst below the process air entry point. These and additional changes are discussed in more detail.

LIQUID SULPHUR DEGASSING PROCESS

Fig. 1: **D'GAASS sulphur degassing process**



Source: Fluor

D'GAASS operation history

The D'GAASS process degassing performance has been very good. All of the over 100 licensed units have met their performance guarantees. There have been a few locations that have experienced some operational issues. The most significant problem has been corrosion in the upper contactor area and overhead piping upstream of the pressure control valve. Level control has been a problem in some units.

Overhead corrosion

Corrosion in the upper contactor and overhead piping is a result of water condensation in the presence of H_2S, SO_2, O_2, and sulphur vapour. Water is present from the oxidation reaction of H_2S and H_2S_x. The presence of oxygen results in a very aggressive corrosive environment when water condenses. Operation under pressure improves degassing performance, but also increases the water dew point. It is therefore essential to maintain the temperature of the contactor shell and overhead piping above the water dew point temperature. Improvements in design to reduce the corrosion potential are discussed in the upgrades section.

Level control

Some units have had problems controlling the level in the contactor. Most of these locations have had problems because radar type level transmitters have been installed instead of the specified capacitance type level transmitters. GAA has only had long term success with capacitance, admittance and nuclear type level transmitters for direct measurement of the liquid level in the vessel. There is a foam disengaging layer on top of the liquid sulphur as air bubbles exit the liquid phase. This foam layer can act like an acoustical tile and affect the radar signal. This is true for both conventional and guided wave radar. The foam layer can be tuned out for a set of conditions, but the foam layer can be affected by multiple impurities, particularly dirt and oils that affect the foam layer thickness and density.

D'GAASS upgrades

When there have been issues with the operation of D'GAASS Units, GAA engineers have worked to develop solutions to address the issues. Some of the major design upgrades in D'GAASS units are addressed below.

Operating pressure

Some of the early D'GAASS units operated at pressures that required utilisation of 2-stage compressors to supply the process air. Through performance testing, it was confirmed that the operating pressure could be reduced to allow using single stage compressors while maintaining less than 10 ppmw residual H_2S in the product sulphur if some design parameters were modified. Lowering the operating pressure also had the positive effect of lowering the water dew point in the overhead gas stream.

Dry air

In earlier installations, some D'GAASS units have experienced corrosion in the upper contactor vessel and overhead piping although the process conditions did not indicate that corrosion could occur. Closer evaluation of the corrosion points indicated it was occurring at cool locations in the vessel and piping such as lifting lugs, pipe supports, etc. For the type of corrosion that was observed, there must be a liquid phase (water) present. Water cannot be eliminated from the process because it is a reaction product from oxidation of H_2S and H_2S_x. However, the amount of water from reaction is much less that the amount of water entering with the process air in locations utilising dedicated air compressors to supply the air. This was particularly the case in locations with normally high to moderate ambient temperatures and high relative humidity. Therefore, the process air requirement was changed to utilise dry, instrument air quality, air. This significantly lowered the water dew point in the overhead gas stream and reduced the potential for corrosion.

SULPHUR
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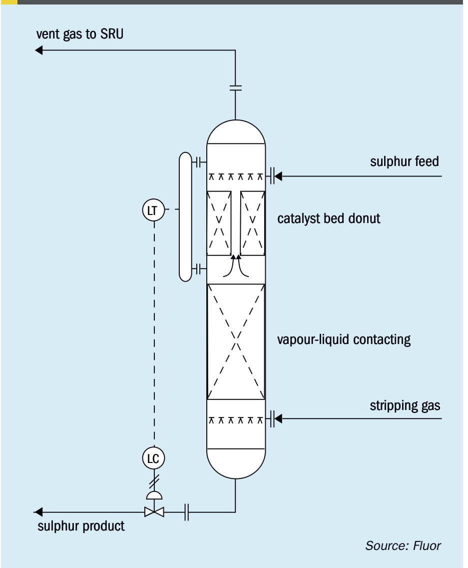
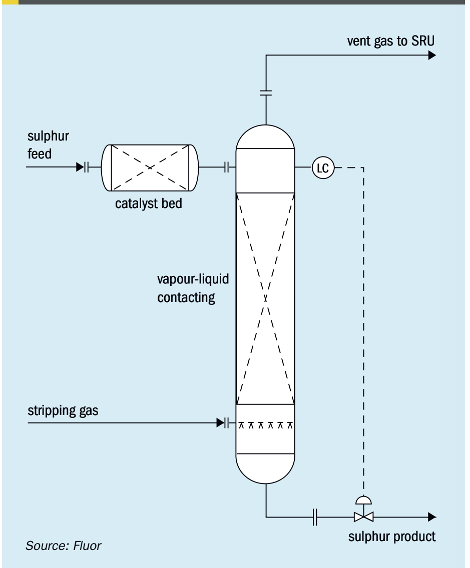
Fig. 2: **D'GAASS contactor with donut catalyst bed**



Source: Fluor

Fig. 3: **D'GAASS contactor with external catalyst bed**



Source: Fluor

Fully steam jacketed contactor

Corrosion issues were a result of cold locations in the contactor and overhead piping where water could condense in the presence of acid gases H_2S and SO_2. With oxygen present, the corrosion was likely sulfurous acid corrosion. Higher alloy metallurgy including Hastelloys were tried, but rapidly corroded in cold locations. ControTrace elements and panels were utilised on the upper contactor and overhead piping, but ControTracing leaves gaps and sections without direct heat, and if the ControTracing is removed for maintenance, it frequently is not reinstalled correctly.

To minimise the potential for cold spots and resulting corrosion, current designs include full steam jacketing of the contactor vessel and overhead piping through the pressure control valve. This assures that there will not be areas that are not directly heated and minimises the potential for corrosion. In the critical overhead area of the contactor and overhead piping, medium pressure steam (7-10 barg/100-150 psig) is being utilised for jacket heating. Higher pressure steam provides additional temperature margin (about 20-35°C/35-65°F) above standard 3.5 barg (50 psig) steam and maintains temperatures above the water dew point.

D'GAASS 3rd generation objectives

D'GAASS design engineers are continually looking for improvements in the reliability and performance of the degassing process. Through better understanding of the potential advantages of solid catalyst promoting the decomposition of H_2S_x, objectives for process improvement were established. These include:

- minimise catalyst attrition from fluidisation/agitation of the catalyst bed;
- reduce the process operating pressure to improve H_2S stripping from liquid sulphur and corrosion potential;
- reduce the required residence time for sulphur degassing through H_2S_x catalytic decomposition and improved H_2S_x stripping;
- easily upgrade existing D'GAASS units with new developments.

Methods to achieve objectives

Avoid upward flow of sulphur and air across catalyst bed

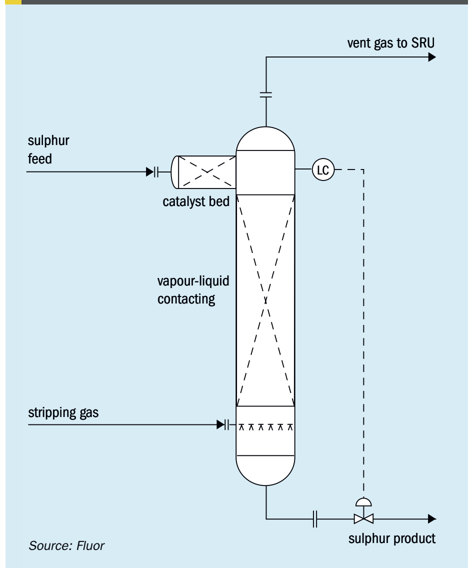
The primary issue with another out-of-pit process has been catalyst attrition from upward flow of sulphur and air through the catalyst. The density of sulphur and the particle density of alumina catalyst are very similar. Therefore, there is a significant buoyant effect from liquid sulphur and upward flow of sulphur and air causes catalyst particles to float/fluidise and grind away at adjacent catalyst particles. This effect is countered by having sulphur flow downward or across the catalyst bed.

Isolate catalyst bed from stripping gas flow

Stripping gas is required to remove H_2S released from the liquid sulphur. However, upward flow of stripping gas bubbles can promote movement of catalyst particles, which causes attrition of the catalyst. In the latest design, stripping gas is isolated from the catalyst bed. Sulphur flows across the bed to promote decomposition of H_2S_x, but air does not flow counter currently to the sulphur until it exits the catalyst bed.

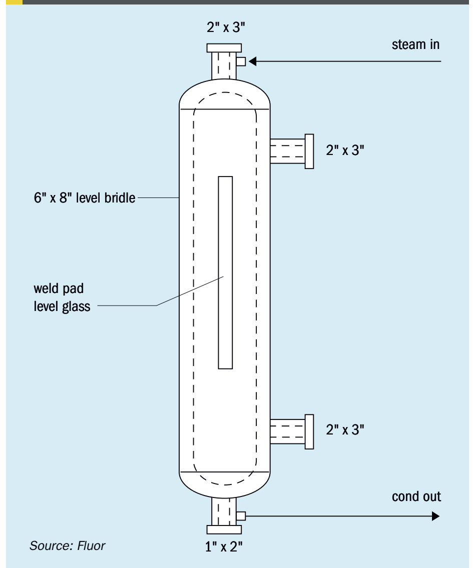
There are alternative configurations that can accomplish the isolation of the catalyst bed from the stripping gas. Fig. 2 illustrates an option in which the catalyst bed is located in a donut arrangement above the main sulphur liquid level. Sulphur is distributed around the donut and gravity flows downward through the catalyst bed. Stripping gas disengages from the main liquid sulphur pool and flows upward through the stand pipe in the

Fig. 4: **D'GAASS contactor with side mounted catalyst bed**



Source: Fluor

Fig. 5: **D'GAASS contactor steam jacketed level bridle**



Source: Fluor

centre of the catalyst bed. Fig. 3 shows an arrangement in which sulphur flows through the catalyst bed that is located in a separate vessel before entering the main stripping vessel. Fig. 4 shows an arrangement in which the catalyst bed is located on the side of the stripping vessel. Sulphur flows horizontally across the catalyst bed before entering the main stripping section of the vessel.

Alternative level measurement methods

The donut arrangement for the catalyst bed shown in Fig. 2 requires a different level measurement configuration than the capacitance probes that have been utilised in D'GAASS units and inserted through the top of the contactor vessel. The best arrangement for level measurement with the catalyst donut arrangement is indirect through use of an external level bridle, see Fig. 5. The bridle is fully steam jacketed (nozzles, valves, and main body). The external level bridle can obviously be used for the other configurations shown in Figs 3 and 4.

The external level bridle allows several options for level measurement, and allows easier application of different types of devices for control and shutdown functions. Level transmitter options include conventional differential pressure transmitters, bubbler type differential pressure, radar, and capacitance. The level in the bridle can also be visually observed by using a weld pad level glass for the main body. A weld pad with a radius curve to match the body is recommended to minimise stress on the glass.

Summary

The D'GAASS 3rd generation process takes advantage of solid catalyst dissociation of H_2S_x to H_2S and sulphur to enhance stripping H_2S from Claus SRU product sulphur. Catalyst attrition is avoided/minimised by utilising sulphur down flow or cross flow across the bed and isolating the bed from stripping gas flow. Stripping is enhanced by operating at lower pressures and sulphur residence times than previous D'GAASS units. Existing units can be retrofitted to 3rd generation operation and at the same time, the processing capacity.

In addition, the D'GAASS liquid sulphur degassing unit can easily be designed and fabricated in the form of a truckable modular unit to mitigate expensive field installation and shorten EPC schedule. Modular units up to 800 t/d require a plot area of only 5 m x 10 m. ■

PHOTO: FLUOR

Truckable module with contactor, cooler and major controls. Up to 800 t/d liquid sulphur processing capacity.

SULPHUR
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MARCH-APRIL 2020

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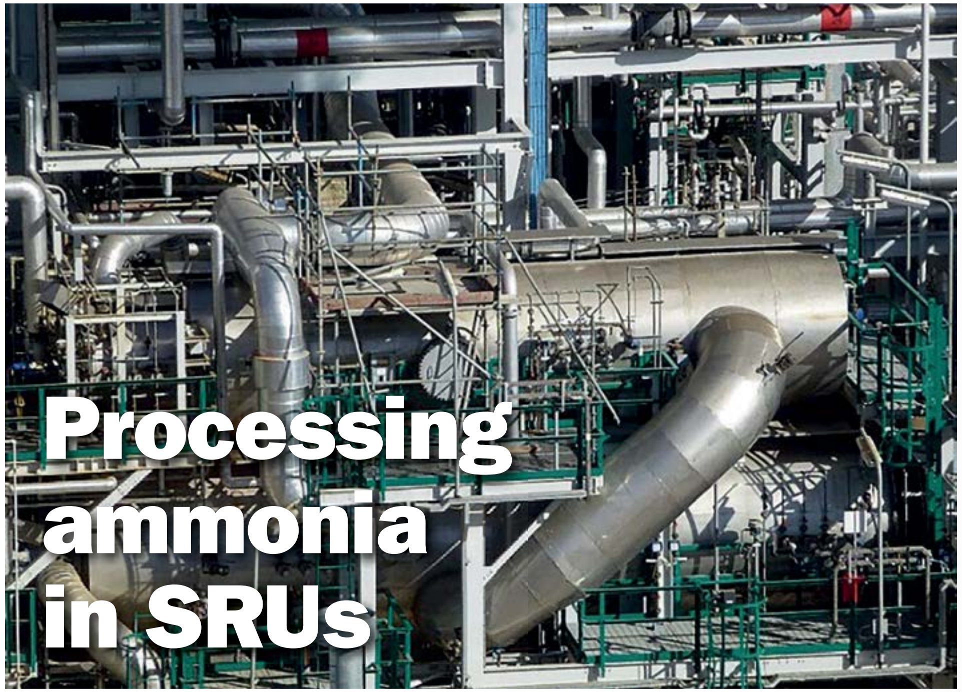


Processing ammonia in SRUs

PHOTO: DUIKER

R. Kranenburg of Duiker discusses the latest applications of SCO units in refineries and petrochemical complexes. The SCO unit is typically integrated in the sulphur recovery unit and is intended for processing ammonia, while also treating the tail gases from the upstream SRU.

Fig. 1: SCO unit – the reducing chamber is positioned above the oxidising chamber.

Duiker has developed its ammonia incinerator to meet market demands for a simple and reliable process that converts ammonia (NH_3) in refineries and petrochemical plants into nitrogen and water. The Stoichiometry Controlled Oxidation (SCO) unit is typically integrated in the sulphur recovery unit (SRU) and is intended for processing ammonia, while also treating the tail gases from the upstream SRU. The heat generated during the oxidation of NH_3 is reused in the downstream thermal incinerator unit to preheat the SRU tail gases. Although the temperature of the tail gases is increased significantly, a small support burner on the thermal oxidiser is often installed to provide additional heat to bring the tail gases to the required incineration temperature.

Today, several SCO units are in operation under various process conditions which prove its ability to completely decompose NH_3. In stark contrast to uncontrolled ammonia combustion which can easily generate thousands of ppm of NOx emissions, the NOx emissions from the SCO unit can easily meet environmental regulations without further treatment. The SCO unit can realise NOx emissions in the range of 50-70 ppm @ 3% O_2 dry.

History

The SCO technology was developed and commercialised in the early 2000s. The first unit was developed for a refinery in Europe with an existing SRU facility. This facility was designed for processing a regular feedstock in terms of sulphur content which had been imported by the refinery for a long time. However, the attractive price of heavier feedstocks later led to the refinery switching to heavier feedstocks. As a consequence the SRU capacity had to be debottlenecked to enable the plant to handle the extra H_2S and ammonia in the feed. Since the plant was only a few years old, it was decided to make modifications to the existing SRU capacity rather than replacing the existing plant. Plot space limitations were also an important consideration for the refinery. After several plant studies had been made, it was determined that the best method was to integrate a dual-stage SWS unit (dual-stage sour water stripper unit) with an SCO unit. Obviously the strategy behind implementing the dual-stage SWS unit is to separate the H_2S from the NH_3 so that the NH_3 can be routed to the SCO unit in order to reduce the feed gas flow to the main reaction furnace. This creates extra space for processing the extra H_2S from the heavier feedstock in the SRU.

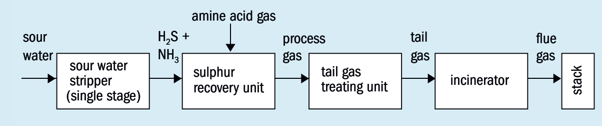
Fig. 2: **Image of an SCO unit – combustion chambers with interconnecting piping**

Source: Duiker

Table 1: **Capex evaluation of conventional and alternative processing of ammonia**

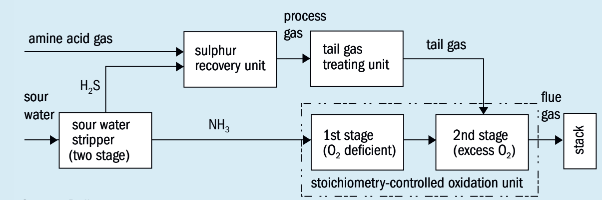
Capex	Conventional processing	Alternative processing
Sour water stripper	100%	160%
Sulphur recovery unit	100%	67%
Tail gas treating unit	100%	66%
Incinerator / SCO	100%	147%
Weighted average	100%	89%

Fig. 3: **SRU line up with TGT unit in which SWS gas is treated in the SRU**



Source: Duiker

Fig. 4: **SRU line up with SCO unit for treating the ammonia containing stream from the dual-stage SWS unit**



Source: Duiker

Fundamental principle of the SCO unit

The most widely supplied type of SCO unit is based on two connected combustion chambers which are positioned one on top of the other (see Fig. 1) to save plot space at the plant site. The ammonia-rich gas from the dual-stage SWS unit enters the first chamber via a dedicated ammonia burner, in which the ammonia is decomposed to nitrogen and water under reducing conditions. The hot effluent exiting this reducing reaction zone is then routed via interconnecting pipes towards the second chamber (Fig. 2), in which the gases are mixed with the relatively cold tail gases from the tail gas treating unit for final treatment in the thermal oxidiser section of the SCO. Additional heat is generated by a support burner on the oxidising chamber to heat up the tail gases to the desired incineration temperature. Regardless of the presence of SRU tail gases or any other gas streams that may be routed to the SCO, an oxidising section is always required to complete the reactions and ensure that there are no unreacted species from the reducing combustion zone. All SCO units are followed by a downstream waste heat boiler which recovers the heat from the process, potentially allowing it to be used in the dual-stage SWS unit to separate the amines in the regeneration column.

Economical evaluation

In recent years more SCO units have been supplied to other refineries. Unlike the first unit all subsequent units have been integrated in new grass roots plants due to the favourable economics of this configuration.

In the following evaluation (Table 1) a 100 t/d SRU is considered with a mixed feed containing approximately 22 vol-% ammonia. The SRU has two catalytic stages and the TGTU is a non amine system, allowing 99%+ sulphur recovery.

The conventional way of processing ammonia via the SRU forms the base case and the costs of the individual components are set at 100%. The impact on capex for the alternative design was then evaluated. The SWS capacity was roughly

SULPHUR
ISSUE 387
MARCH-APRIL 2020

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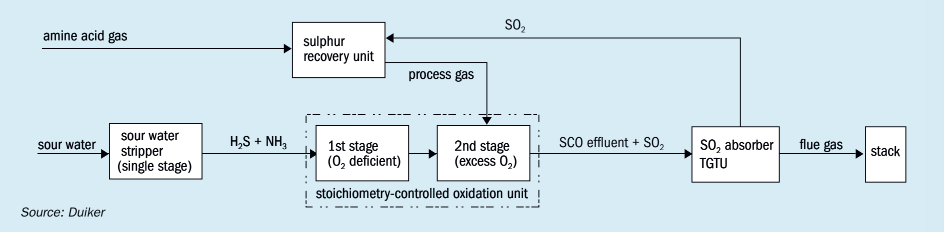
Fig. 5: **SRU line up with SCO unit for treating sour water stripper gas from a single-stage stripper**



Source: Duiker

135 m³/h and converting it to a two-stage design resulted in a capex increase of approximately 60%. In the conventional processing route, the process gas capacity exiting the main reaction furnace was approximately 22,200 kg/h. In the alternative processing scheme the process gas capacity exiting the main reaction furnace was approximately 14,250 kg/h. The resulting decrease in capex of the SRU and TGTU was about 33%. The capex for the SCO unit was approximately 47% higher than the conventional incinerator. The weighted average of these four components yielded an 11% more favourable capex for the alternative processing route.

The opex evaluation was driven by three main items: fuel, electricity and steam. As ammonia is utilised as the fuel for the incinerator in the alternative processing route, 465 kg/hr of fuel gas is saved in the alternative design. With regard to electricity, the main impact comes from the blower consumption, which is reduced by approximately 0.12 MW/hr in the alternative route. The combined sum equates to annual savings of approximately €450,000. The steam balance in the alternative processing route is of course less favourable than in the original design from both a consumption and production standpoint. More steam is consumed due to the dual-stage SWS unit requirements and less steam is produced due to the reduced hydraulic load of the SRU. As no steam costing data was available for this specific plant, the economic impact is not evaluated.

Although it is possible to combust high concentrations of ammonia in the main reaction furnace of a SRU, there are technical considerations (namely achieving a high enough temperature), which favour alternative processing of the ammonia. For feed streams containing high amounts of ammonia, the hydraulic load involved with processing this ammonia in the SRU and thus the capex, definitely favour alternative processing. Through the use of a Duiker SCO unit, licensors and end-users have the opportunity to process the ammonia stream in a separate ammonia incinerator rather than the main reaction furnace, leading to significant savings in capex, while providing a more reliable integrated plant.

Fig. 3 shows a schematic of a SRU line up with TGT unit in which SWS gas is treated in the SRU.

Fig. 4 shows a SRU line up with SCO unit for treating the ammonia containing stream from the dual-stage SWS unit.

Ammonia use for fuel or fertilizer

As mentioned earlier, the ammonia from the dual-stage SWS unit is used as fuel in the SCO unit. Since the heat released by the combustion of ammonia is used for heating up the tail gases from the SRU, the quantity of fuel gas used in the thermal oxidiser will be greatly reduced. This also has a positive effect on the reduction of CO_2 emissions from the stack. However, despite these benefits one could argue that since the NH_3 is separated from H_2S by the dual-stage SWS unit, it would make more economic sense to use it as a feedstock for creating ammonia fertilizer rather than using it as a fuel for the SCO unit. There are indeed a small number of plants in the world where ammonia is transported via a pipeline from the refinery as a raw material for creating fertilizer. Unfortunately the economics of this routing are not known at the time of writing this article.

Ammonia is produced on an industrial scale via the Haber Bosch process. By comparison, the amount of ammonia produced as a by-product in refineries is negligible and must be completely free of H_2S before it can be safely used as a raw product for further processing. From an economic point of view the transportation of ammonia is only considered feasible if there is ammonia demand in the direct vicinity of the refinery.

Current developments

In the most recent application of SCO technology it has been integrated in a grassroots petrochemical complex for handling an ammonia-rich stream from an upstream process containing a few percent of sulphur. Since oxidising this stream in a standard thermal oxidiser would lead to high NOx and SOx emissions from the stack, the SCO routing was further evaluated by the licensor in combination with a SO_2 scrubber to handle this stream. Further research is currently being carried out to investigate the effect of greater amounts of sulphur on the operation of the SCO unit and how this affects the decomposition of ammonia. Results to date are positive indicating that larger amounts of sulphur can be processed by the SCO which could make it an attractive alternative for directly processing gases from a single-stage SWS unit. Duiker also sees the potential for realising even lower NOx emission values.

Fig. 5 shows a SRU line up with a SCO unit for treating sour water stripper gas from a single-stage stripper. An SO_2 absorber is attached to remove the sulphur species from the outlet stream of the SRU (without TGT) and to remove the sulphur species from the outlet stream of the SCO unit. ■

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ISSUE 387
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Redox reborn – the Valkyrie™ process

PHOTO: STREAMLINE INNOVATIONS

J. C. Bourdon, F. H. Brown and **P. J. Photos** of Streamline Innovations Inc. present the development and commercialisation of the Valkyrie™ process, which employs new chemistries and advanced control systems to remove H_2S from natural gas at size scales ranging from single wells to entire fields, providing an operationally sustainable and commercially attractive alternative to standard H_2S removal technologies.

Above: *15 long t/d Valkyrie™ plant in west Texas.*

While the demand of natural gas in industrial and commercial processes has increased exponentially in the past few decades, its abundant supply and therefore relatively low cost have led to a need for efficient and economic removal of hydrogen sulphide (H_2S) from the gas stream. Gas production has traditionally concentrated on sweet gas fields, but their depletion has shifted the focus towards sour greenfields and enhanced recovery in soured brownfields. In both cases, however, the large capital costs and lengthy construction times to build Claus-based sulphur recovery units (SRUs) or acid gas injection wells (AGIs) as well as the necessary sour service equipment associated with treating has caused many producers to examine treating H_2S as close to the wellhead as possible. However, at-well or near-well treating can be costly from an operating standpoint as treating options for modest quantities of H_2S are limited to scavenger-based treatment, such as triazine, iron oxides, or zinc oxides, historically used only to treat small quantities of sulphur. This has left producers with a decision between high capex-low opex facilities with long lead times or low capex-high opex scavenger-based units.

This capex-opex balance has been an especially difficult problem for producers when the quantity of H_2S that needs to be removed is not significant enough to warrant the extensive capital investments associated with an SRU or AGI, but the chemistry costs for scavenger-based treating can be prohibitive.

Amine has always been a robust and attractive solution for removal of H_2S and CO_2 from gas streams, but the tail gas produced by that process requires either disposal in an AGI or processing through an SRU. Even the use of a SRU requires further treatment, as the tail gas from that process contains too much H_2S for atmospheric venting or flaring. Thus, any solution involving amine treatment requires a secondary treatment methodology, each with its own cost and limitations. Further complications with downtime of AGIs[1], as well as regulatory hurdles required for their construction and maintenance add an additional complexity in determining the correct methodology to remove H_2S[2].

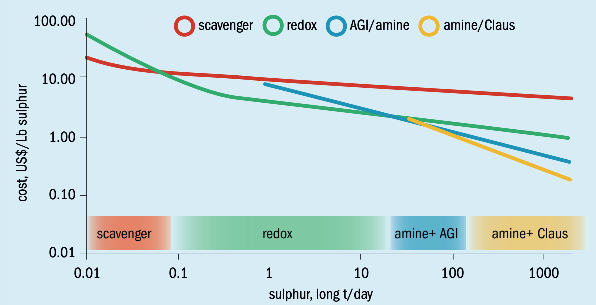
A comparison of technologies is given in Table 1. The opex and capex of each technology can then be further analysed to yield an effective cost per pound of treatment to give a range of sizes for which each technology is most economic (Fig. 1). Redox occupies an important range between roughly 0.1 – 20 long t/d in sulphur treatment; not coincidentally, this range is also the fulcrum of the opex-capex conundrum.

H_2S removal using oxidation-reduction chemistries therefore have long been an attractive solution, as the construction costs are modest compared to SRUs or AGIs, and their operating costs are a fraction of scavengers due to their regenerative chemistry. A number of attempts at commercialisation of such processes have been made – Sulferox™, LO-CAT™, and Stretford™ – however, these processes have evaded ubiquitous usage due to limitations in capital construction costs, operative sustainability, and/or the use of chemistries that are difficult to manage and by-products that are hard to dispose of.

Table 1: **Summary of H_2S removal & recovery technologies**

Technology	Applicable range (long t/d)	Capex (USD)	Opex USD/lb sulphur	Waste/products	Risks
Primary treating technologies					
Scavenger (e.g: Triazine, SulfaTreat™)	0.1–1	<$300,000	$6.00–$15.00	Dithiazine, "spent scavenger"	Spent scavenger malodorous and hazardous to dispose
SRU (Claus)	20+	$25 million–$30 million+	$0.10–$0.25	Tail gas (30%–100% H_2S), elemental sulphur	Long construction time: (2+ years); requires secondary treatment; minimal turndown
Amine (MDEA, MDEA-DEA)	1–20	$2 million–$20million+	$0.05–$0.20	Tail gas (30%–100% H_2S)	Requires secondary treatment
Redox (Valkyrie™, LO-CAT™, Sulferox™ Stretford)	0.1–20	<$1 million–$10 million +	$0.50–$5.00	Elemental sulphur	
Secondary treating technologies					
AGI	20+	$20 million–$30 million+	$0.01–$0.10		Low uptime; HSE hazard
TGTU	20+	$20 million–$30 million+	$0.05–$0.25	Elemental sulphur + 10ppm H_2S	Long construction time
Redox	0.1–20	<$1 million–$10 million+	$0.50–$5.00	Elemental sulphur	

Fig. 1: **Comparison of treating costs per pound of sulphur**



Source: Streamline Innovations

The history of redox

A variety of chemistries have been used to employ the redox process to treat H_2S. Typically, any chemistry whose reversible states have reduction potentials between $H_2S \rightarrow S_{\downarrow} + 2H^-$ and $2H^- + O_2 \rightarrow 2OH^-$ can be used as a pseudo-catalyst in the reaction. The first successfully commercialised process was the Stretford process developed in the late 1940s which used a chelated vanadium cation as the catalyst. However, problems with vanadium handling as well as the formation of hazardous by-products in the reaction restricted its adoption. The Sulferox and LO-CAT process, developed in the 1970s and 1980s, employed chelated iron rather than vanadium, which reduced the production of toxic side reactions. These processes showed some commercial success but eluded ubiquitous adoption due to operational difficulties, including the formation of emulsions which were difficult to manage, and wide variability in operational efficiencies. Nonetheless, these processes are still used, boasting operational successes from 0.1 long t/d of sulphur up to 20 long t/d.

The primary advantage of the redox process is that the chemistry is regenerative; many metals can work, but in the case of chelated iron, Fe^{3+} is reduced to Fe^{2+} and oxidised back to Fe^{3+} continuously, with the chelant keeping the cations from precipitating throughout the process. The makeup volumes, and therefore the treatment cost, depend almost exclusively

SULPHUR
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MARCH-APRIL 2020

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on the management of chemical losses. Losses occur through either:

- degeneration of the chelant which keeps the iron in solution;
- inadvertent disposal of chemistry with the elemental sulphur removal;
- unexpected carryover of chemistry out of the system, exacerbated by foaming;
- operational losses that occur during maintenance.

Managing these channels ensures an extremely cost-effective method to remove H_2S.

A further advantage of redox is that the reactions used to treat H_2S occur at a wide range of pressures and at ambient temperature, and therefore do not require any compression or heating of the gas, imparting a low-energy consumption.

Despite these advantages, redox has historically only gained a niche market in the oil and gas world, as it also has a number of technical and economic challenges that made it a "less than optimal" choice for H_2S removal. The choice of first generation chelants such as EDTA, and second generation chelants such as HEDTA and NTA are subject to degradation during the oxidation process to form oxalates, which lead to iron precipitation and chemistry loss. The oxalates themselves further reduce operational efficiency by imparting a stickiness to the elemental sulphur, which must be landfilled for disposal. Finally, the system is subject to the development of highly stable Pickering emulsions, due to the presence of multiple states of matter (solid sulphur, aqueous solution, hydrocarbon condensate, and natural gas and/or air), which further create undesirable solids at the tops of vessels and promote carryover out of the system.

Revisiting redox – the Valkyrie™ process

The Valkyrie™ process was developed in the late 2010s to mitigate many of the issues associated with the redox process. This process retains the chelated iron pseudo-catalyst, but extends the life of the complex with the addition of three important changes:

- selecting a novel chelant that is resistant to degradation, thereby imparting a longer circulation time, lower make-up rates, and lower oxalate formation;
- using bespoke defoaming surfactants and wetting agents to promote sulphur settling, minimise chemical loss in the filter, and destroy Pickering emulsions; and
- employing advanced process control techniques, including machine learning and artificial intelligence, as well as proprietary instrumentation to allow monitoring and control of the extent of reaction, thereby increasing chelant lifetime and optimising operation.

Chelant selection

Towards the end of the 1990s, new classes of chelants were developed to replace the use of phosphate-based rinsing agents in dishwashing detergents, which were ultimately banned in most countries by 2011. These 'third generation' chelants (first being chemicals such as EDTA and citrates, second being derivatives such as HEDTA and NTA) showed significant advantage over its predecessors with a greater pKa towards metal cations, eco-friendliness, and robustness of use. Not surprisingly, a number of these showed applicability in other industries, including water treatment and as scale inhibitors. After screening a number of these molecules, it was discovered that a subset can also function as iron chelates in the redox process. These species can be further augmented with the addition of protective moieties on the molecule to impart a resistance to hydroxyl degradation. The development of this proprietary chelant - called Talon™ – is a key differentiator used in the Valkyrie™ process.

Surfactant selection

Redox-based sulphur recovery from natural gas has eluded full commercialisation partially due to the complexities of the multiphase nature of the process. The presence of multiple phases – oil, water, solid, and gaseous – promotes the creation of foams and emulsions that can cause operational difficulties, namely, pump cavitation, clogging, and sensor degradation.

The multiphase composition of the streams is further complicated by a wide swing in pH and temperature often seen in day-to-day operations. Historically, these swings have restricted the use of any single surfactant and/or demulsifiers to abrogate the challenges encountered.

While the use of anionic surfactants have been reported to be used in such systems, they are non-ideal because of their extreme foaming tendencies. Classical defoamers were also avoided as they were discovered to interfere with the oxidation-reduction chemistry. Additionally, the addition of such defoamers restricts the agricultural applications of the produced sulphur.

The novel blend of surfactants act in concert to inhibit emulsion formation, promote settling of sulphur, prevent foaming, and remove the solids phase from the system. Additional chemicals augment the process by leveraging their lower costs, slower kinetics and emulsion-breaking capabilities providing a cleaner filter cake.

Control systems

In order to maintain the optimal regenerative capabilities of the system (and therefore minimise operation costs), it is necessary to maintain the extent of reaction of the two chemical steps within a narrow range. To achieve this level of control, an 'intelligent', tiered control schema was developed that employs 1) a typical PLC, 2) a local computer to perform complex calculations on-site, and 3) additional computers in the cloud that can perform extended calculations to maintain system health (Fig. 2).

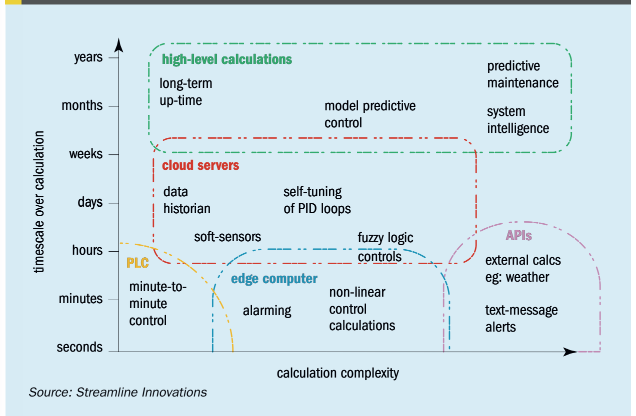
The PLC is configured with standard interlocks and basic controls to ensure that the system maintains the operation of the unit and functions moment-to-moment without interruption. However, much of the complex algorithms and calculations are beyond the capabilities of the machine and are 'outsourced' to a local computer running Python. Examples of such scripts include nonlinear calculations to maintain circulation rate and 'soft sensor' calculations that determine intermediate values used in the process. The system is designed such that the PLC is capable of maintaining the operation of the unit even if the Linux computer fails. This ensures that the system keeps the robustness of a PLC with the intelligence of modern-day computing.

Beyond the local calculations, the intelligent control system is able to locally store data and sync with servers in the cloud bidirectionally. This allows operators to maintain, troubleshoot and operate the unit completely by mobile app; when issues occur, text messages are automatically sent and the operator merely needs to login to the app to review the issue, examine earlier performance data and trends, and change operator parameters accordingly without having to go to site.

With such cloud capabilities, additional, non-critical calculations can be done off-site. These servers are not limited by processing capacity or robustness; they are cloud machines that can be expanded to meet the processing demand ad hoc. Examples of some of these calculations include the use of machine learning to auto-tune PID loops using multivariable regression analysis which report back to the local machine and FFT calculation on pumps to predict maintenance requirements, which automatically trigger maintenance tickets. Additional third party APIs can also be employed, for example in using forecasted temperature from weather services in pre-empting process temperatures or emergency shut down procedures employed during tornado warnings.

At the highest level of computing power, the reporting tools can accumulate data from all the machines, and provide operators and engineers with up-to-the-minute data. Relevant calculations between various units within one field that allow the units to 'learn' from one another, and improve their own autonomous operations.

Fig. 2: **Intelligent control schemes**



Source: Streamline Innovations

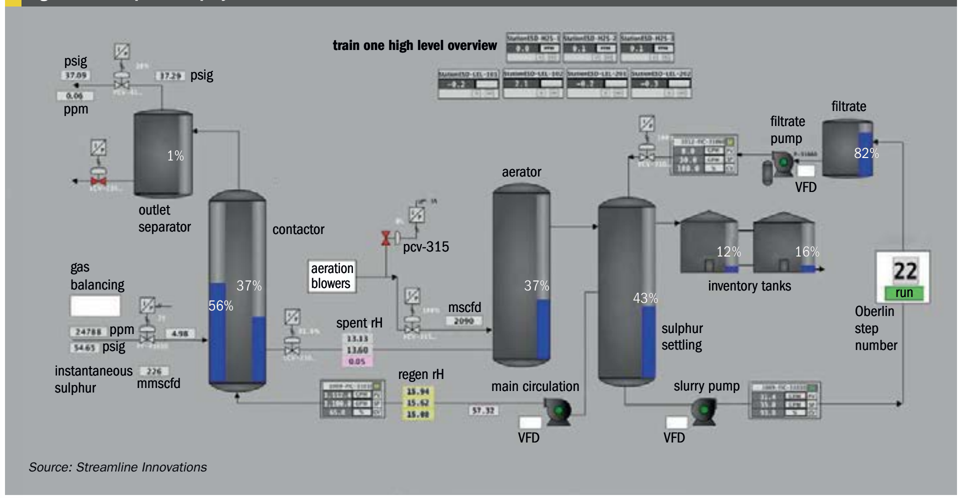
Since the data is stored locally as well as in the cloud, the access to the system via the local Linux machine can viewed as the 'primary' human interface to the system. A 'classic' HMI - wherein the screen interfaces directly with the PLC itself, is limited in the number of access points and often requires proprietary equipment to control the unit. By interfacing with the Linux computer, any computer on site or on the web, properly authenticated, can operate the unit. With an ad hoc Wi-Fi network being broadcast on site, operators can use tablets in the field to access the HMI and troubleshoot, perform function checks on equipment, and even log events and information that is reported back with the raw data (Fig. 3).

The Valkyrie™ 3-step sulphur extraction system

The result of these changes means that the 'traditional' redox configuration can be employed to treat the H_2S. The process flow diagram (Fig. 4) is similar to the Sulferox and Stretford processes.

Sour gas flows through a vapour-liquid separator and inlet filter coalescer which remove any hydrocarbon droplets. The clean, sour gas then flows into the contact tower where it contacts the Talon™ chemistry. The gas, free of hydrogen sulphide, flows out of the contactor and through a sweet gas vapour-liquid separator and outlet

Fig. 3: **Control panel display**



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CONTENTS

SULPHUR
ISSUE 387
MARCH-APRIL 2020

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filter coalescer. The Talon™ chemistry containing elemental sulphur solids flows to the Talon regenerator where air is added and the Fe^{2+} is oxidised to Fe^{3+}. The regenerated Talon flows to a settling tank where the sulphur is settled and sent to filtration removing sulphur and returning the liquid Talon chemistry back to the settling tank. Clean Talon chemistry is pumped back into the contactor.

Step 1 – Combine sour gas containing H_2S with "lean" chelated iron and produce elemental sulphur and "rich" chelated iron (Fig. 5).

Step 2 – "Rich" chelated iron flows to an aeration basin where it reacts with oxygen (in air) to release water and "lean" chelated iron (Fig. 6).

Step 3 – Elemental sulphur is sent to a filter press which drops sulphur cakes into a roll-off bin (Fig. 7).

Fig. 4: **Valkyrie™ process flow diagram**

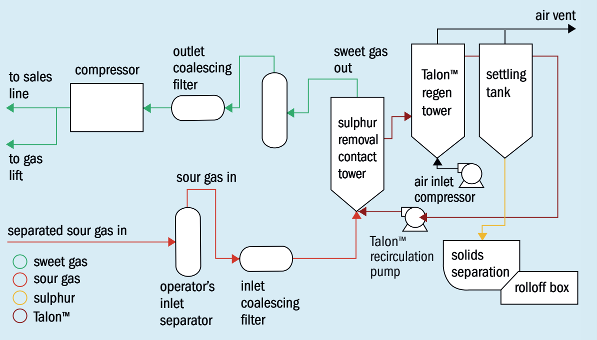

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Fig. 5: **Step 1 – REDuction**

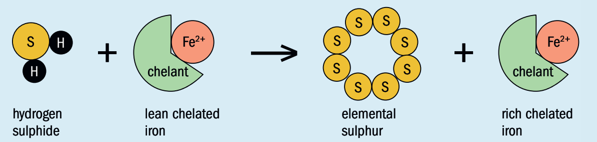

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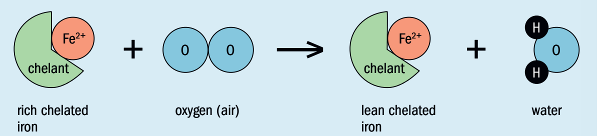
Fig. 6: **Step 2 – OXidation**



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Valkyrie™ applications

The Valkyrie™ redox process has several applications in oil and gas processing (Fig. 8). Since the process completely converts H_2S to elemental sulphur regardless of H_2S concentration, flow rate, or pressure, any sour gas stream between the wellhead and the pipeline, including tail gases, can be treated. Direct treatment – in which sour natural gas is sent through the process – can be done either at the wellhead using a small skid-based unit, or at a gathering facility with a custom-designed plant. Secondary treatment, i.e., post amine plant separation, can be performed on tail gases, giving the option of completely destroying H_2S without the need for an AGI or SRU.

If NACE compression exists, applications at high pressure either direct or after amine treatment to concentrate the sour components into acid gas (H_2S and CO_2) can provide an economical alternative to acid gas injection, Claus sulphur recovery, or other technologies to remove or recover H_2S.

Valkyrie™ operational results

To date, Valkyrie™ direct treat applications have been operating across west and south Texas at pressures between 30 psi to 180 psi, with designs in place to operate up to 1,440 psi, and flow rates between 0.75 and 25 million std ft³/day.

The process has successfully and continuously treated H_2S levels from 200 ppm through 40,000 ppm, with a tail gas treater designed to handle 40% H_2S under construction. In terms of sulphur loading, the Valkyrie™ process has demonstrated successful treatment from 0.1 long t/d up to 16 long t/d. All units have reported greater than 99% uptime, with a total number of cumulative operating hours of more than 40,000 hours. Since 2018, Valkyrie™ units have treated and produced over 9 million lbs of sulphur, or more than 4,000 long tons of sulphur. At no time was the level of H_2S measured in the outlet gas stream greater than 4.0 ppm, and it was less than 1.0 ppm for greater than 99.9% of the operating time (Fig. 9).

Fig. 7: **Sulphur filter cake**

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Fig. 8: **Sour gas treating options**

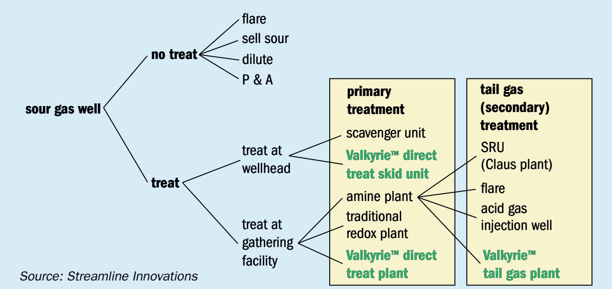

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Fig. 9: **GasTec tubes – sour gas in, sweet gas out (black indicates H_2S ppmv)**

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A summary of Valkyrie™ units that are in operation to date, as well as those under construction are given in Table 2.

The sulphur quality was analysed and found to be 99%+ purity, and can readily be used as an agricultural fertilizer. At 5-10 µm in diameter, the particles are ideally suited for integration into soil. The filter cake cleaning process removes nearly all the chemistry, and the cake retains about 15%-30% moisture, which can undergo further dehydration if necessary. The only other components found in the solid waste stream are trace amounts of hydrolysed surfactant, which ultimately biodegrades within days of disposal. The vent stream, i.e., that from the aerator, was also analysed and found to contain no H_2S.

Case studies

Case 1 – Wellhead treating

An operator in South Texas was seeking to reduce lease operating expenses by replacing Triazine-based scavenger with an alternative technology. One site was selected as part of an early development program, and two subsequent sites were then chosen for commercial units after the successful pilot. The total gas flow rate for all three

Table 2: **Summary of Valkyrie™ units in operation or under construction**

Plant	Configuration	Service time	Gas flow rate (million std ft³/d)	Line pressure (psi)	Inlet H_2S concentration (ppmv)	Average daily production (long t/d)
A	Gen 1.0 skid-based direct treat	26 months	1.2–2.0	100	2,000–4,000	0.15
B	Gen 2.0 skid-based direct treat	14 months	3.0–5.0	130	800–1,500	0.23
C	Gen 2.0 skid-based direct treat	14 months	7.0–7.5	150	800–1,500	0.34
D	2 Train sustom-built plant	10 months	8.0–12.0	60	20,000–40,000	12.5
E	Gen 2.5 skid-based direct treat	1 month	0.5–1.0	130	3,000–4,000	0.10
F	Gen 2.5 skid-based direct treat	1 month	3.0–4.0	70	200–1,000	0.22
G	Gen 2.5 skid-based direct treat	1 month	4.0–6.0	70	1,500–2,500	0.54
H	Gen 2.5 skid-based direct treat	1 month	4.0–6.0	70	2,500–5,000	0.71
I	Tail gas treater	Under construction†	60	1,000 (D) 30 (T)‡	500 (D) 360,000 (T)‡	1.1
J	Tail gas treater	Under construction†	60	1,000 (D) 30 (T)‡	500 (D) 360,000 (T)‡	1.1
K	Tail gas treater	Under construction†	60	1,000 (D) 30 (T)‡	500 (D) 360,000 (T)‡	1.1
L	1 Train custom-built plant	Under construction†	15	60	25,000	14.0
M	2 Train custom-built plant	Under design†	400	1,000	1,000	15.0

†Design basis ‡(D) Direct treat pressure; (T) Tail gas pressure

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ISSUE 387
MARCH-APRIL 2020

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sites was 13 million std ft³/day of gas containing an average of 1,300 ppm of H_2S. The total sulphur production was approximately 1,400 lbs/day of sulphur (Fig. 10).

The result saw the average site treating costs reduced by 43%, including the amortised capital expenditure of the equipment. The units have operated continuously with 99% uptime since their commissioning in late 2018.

Case 2 – Large plant treating

A client in West Texas was seeking to treat H_2S at its gathering facility which was initially determined to be 25 million std ft³/day and contain approximately 1.6% (16,000 ppm) H_2S, for a total of approximately 15 long t/d of sulphur. The plant was designed, built, and commissioned in a period of 29 weeks. Upon start-up, the H_2S level increased significantly reaching values of over 40,000 ppm, and levelling down to approximately 20,000-25,000 ppm. The unit was able to treat this higher concentration to zero ppmv H_2S outlet, and once the client was able to reduce the gas flow rate to 12-15 million std ft³/day, the unit has treated the gas sustainably for over ten months.

An expansion (debottlenecking) of the unit is currently underway to extend the capacity of the existing units to 40,000 lb/day or 17.8 long t/d. In addition, a third train is being constructed (Fig. 11) increasing the total treating capacity to 40 million std ft³/day and 71,360 lb/day or 31.8 long t/d of sulphur. This expansion has allowed a 150% expansion of the gathering field within a very short time, unlocked an additional 3000 barrels of oil per month based on treatment capacity of the associated gas; all at a savings of $2million per month compared to triazine.

Fig. 10: **1.0 Long t/d Valkyrie™ skid**

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Conclusion

As existing wells are aging and new sweet fields become scarce, H_2S will become a greater concern for operators, and there will be a greater need in the future to find effective solutions. The liquid redox process to remove H_2S from natural gas itself is not new, but prior attempts at commercialisation have been limited by operational and control issues. With current technology this article presents a workable economic solution that is able to remove H_2S in an effective, low-cost, and green way. These self-contained automated units operate at both large and small scales, providing operators with a flexible and scalable solution that can be rapidly delivered to the field.

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Fig. 11: **Large Valkyrie™ plant (31.8 long t/d) under construction**

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MARCH-APRIL 2020

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ISSUE 387
MARCH-APRIL 2020

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