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Number 379
November | December 2018

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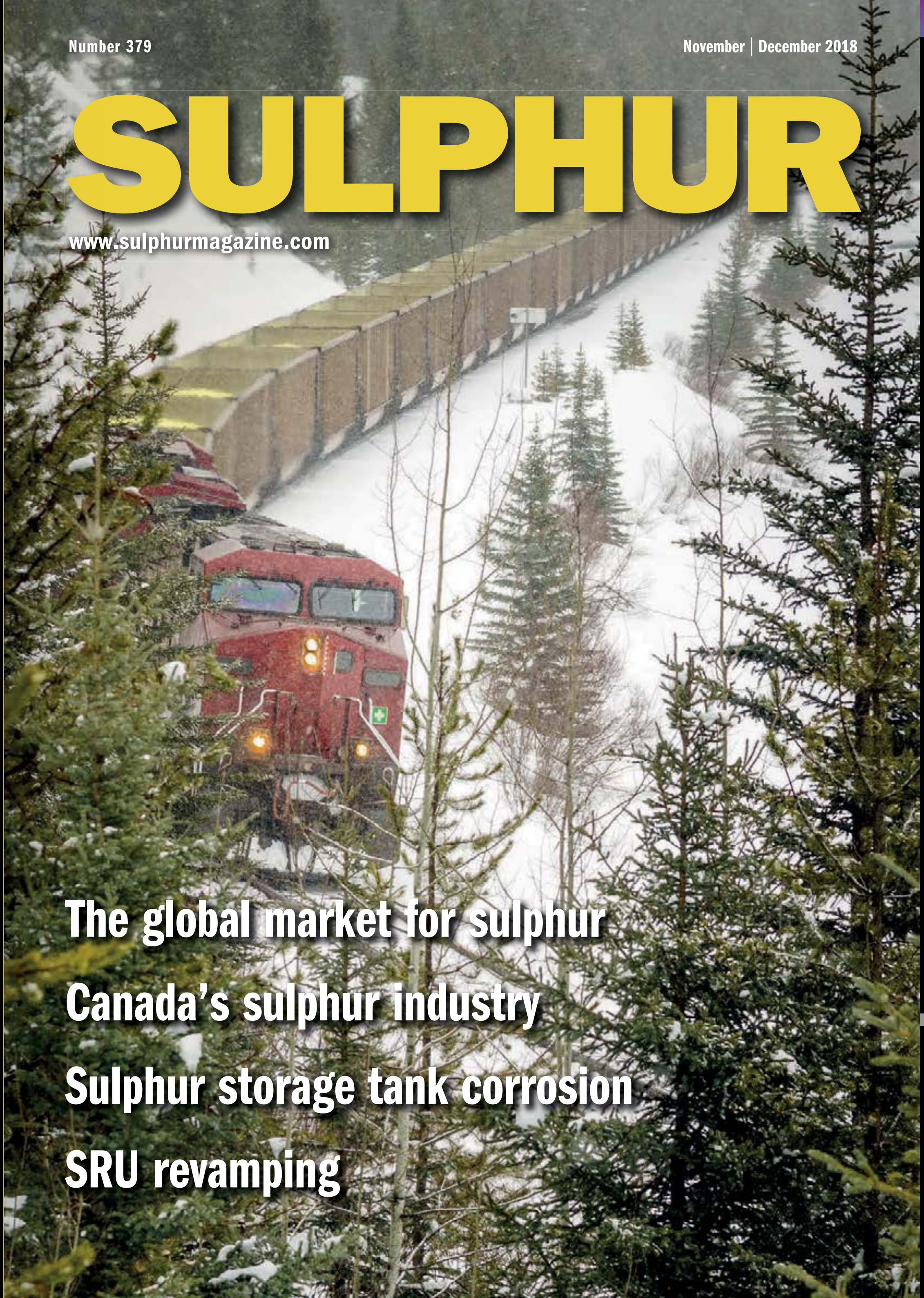

The global market for sulphur

Canada's sulphur industry

Sulphur storage tank corrosion

SRU revamping

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Cover: *Sulphur transported via rail. istockphoto.com/AlbertPego*

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Back to the mines?

At CRU's Sulphur and Sulphuric Acid conference in Gothenburg in early November, just before this issue went to press, the presentation on the next few years for the sulphur market noted that the current surplus of sulphur might be a phenomenon that only lasts for a couple more years, before the market moves back into deficit again, due to continued growth in the processed phosphate sector. But more arrestingly, Peter Clark, formerly of ASRL but now operating his own consultancy business, looked to the much longer term future for sulphur, and whether there would be enough of it.

One factor in this assessment is so-called 'peak oil'. The concern about global oil production reaching a peak has been a concern ever since M King Hubbert wrote his famous 'Hubbert Curve' paper in 1956, predicting that peak oil production would be reached in the 1970s. The most recent 'peak oil' scare came about a decade ago, based on falling production in major Saudi and other reservoirs and China's rapidly rising consumption, but concern has receded as the Chinese economy has slowed and US tight oil production has stepped into the gap. Now concern has transferred instead to peak oil demand. Oil consumption in the developed world has been falling since about 2005, but this has been balanced by increasing consumption in the developing economies, especially in Asia. But as these economies mature, especially in terms of vehicle ownership, and there is more focus on fuel economy and alternative fuels and electric vehicles, so oil demand is also likely to mature and peak there as well, from which point there will be a long slow decline in oil consumption, and hence production. Where this peak will come is anybody's guess, but the consensus of Shell, BP, Exxon, Chevron, DNV and the International Energy Agency is somewhere between 2025 and 2040. And unless there is a major switch from sweet crude to oil sands processing, that will cap sulphur output from oil at about that point, at somewhere in the region of 35-40 million t/a.

On the natural gas side, it is harder to see a 'peak gas' demand in the next couple of decades. Nevertheless, the current crop of sour gas fields that are being exploited in China, Central Asia and the Middle East will also start to decline by that time, and even if they are replaced by new sour gas processing, that may only mean that sulphur output from sour gas is maintained rather than increasing. Peter noted that the projected sulphur demand in 2050 would be in the region of 100-115 million t/a. If oil-based production is capped at 40 million t/a, that leaves up to 65 million t/a to come from sour gas – more than double the current amount and therefore probably not feasible.

This could well leave a gap of up to 20 million t/a of sulphur demand. Some could come from smelter acid production, which also continues to increase, and might significantly increase the size of the merchant sulphuric acid market, but otherwise the only solution would be to turn back to mining sulphur. Then the question becomes – can we actually mine enough sulphur to meet demand? Peak sulphur output from mining came in about 1975, before it was overtaken by sulphur recovered from oil and gas processing, but in that year it stood at only about 12 million t/a. If even that proves not to be enough, or not enough at reasonable economic prices, he said, there might need to be new routes to produce phosphate fertilizer – perhaps using nitric instead of sulphuric acid, or pyrometallurgical production like JDC Phosphate's Improved Hard Process. Perhaps, Peter suggested, we might even start tapping ultra-sour gas fields not for their methane content, but for the hydrogen sulphide instead. An example worked through with co-author Angie Slavens of UniverSul Consulting indicated that at current costs, a long-term sulphur price of around $250-300/t might be sufficient to justify such an investment. It would be a very different sulphur industry from today's, but then today's industry is a very different one from the way it was 30 years ago. ■

> **We might even start tapping ultra-sour gas fields not for their methane content, but for the hydrogen sulphide.**

Richard Hands, Editor

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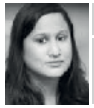
Price trends



MARKET INSIGHT

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

SULPHUR

The global price run up continued through to October, with export prices firming by around 30% since the start of the third quarter. Fourth quarter contract negotiations yielded increases across the board on the back of tight supply and reflected the bullish sentiment from producers. Buyers began to start showing signs of resistance however towards the end of the month, with a question mark over import interest in key market China. As a result, expectations for November were slightly softer, with a downward price correction anticipated.

Middle East producer sulphur prices for October were posted up while November posts tracked back. In Qatar, Muntajat announced its November Qatar Sulphur Price (QSP) at $165/t f.o.b., a $5/t drop on October. This was below the last achieved tender from the supplier ex-Ras Laffan, awarded at $170/t f.o.b. but reduced interest from end users led to the correction. In Saudi Arabia, Aramco Trading (ATC) set its November price at $168/t f.o.b., a minor decrease of $2/t on October.

Spot prices in China trended in the $180s/t c.fr at the high end of the range from September and through October, mirroring prices a year earlier. Sulphur stocks at the nine major ports in China climbed to 1.7 million tonnes in October, a signal for potential price erosion. November arrivals were expected to be low at the start of the month, with end users likely to look to stocks for any short term requirements. Buyers' retreat to the sidelines has put pressure on producer prices and is likely to remain a leading factor in the how long the price correction is sustained. Sulphur production in China has been on the rise in 2018, driven by increased output from both oil and gas plants, and the market has continued to recover following the dip seen in 2015-2016 from a slowdown in gas based production. The rise of domestic sulphur projects in China could become a major market bear factor as the need for imported sulphur is likely to be impacted in the coming years.

Indian import prices for sulphur followed international trends, rising to highs in the $190s/t c.fr on the back of purchase tenders. A short market lull was expected through the early part of November owing to buyers being covered by previous purchases and the Diwali festival. PPL awarded a tender for a 30,000 tonne sulphur cargo for November arrival in the high $180s/t c.fr. Other deals were heard concluded in a similar price range at the end of October. Further tests to the market were expected in the latter part of November. Demand in the domestic market has been strong due to the sugar season, with this demand met by local refiners. Indian sulphur imports in January – August 2018 totalled 767,000 tonnes according to customs data, up by 2% year on year.

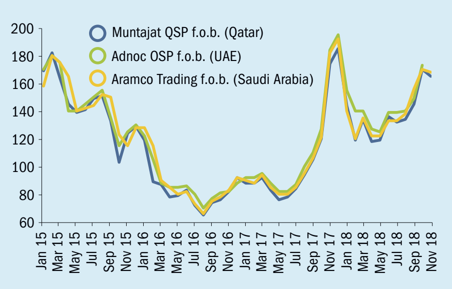
The situation in the Black Sea remains tight as logistical issues persist. Vessel availability has been limited through much of 2018 and has contributed to the tighter market. The winter season is approaching and during this time the seasonal closure of the Volga Don waterway will likely put further pressure on supply and support pricing into the new year.

Brazil remains a bright spot for sulphur trade. In January – September 2018 total imports were up at 1.8 million tonnes – an increase of 14% year on year. Most supply is from the US – with over 600,000 tonnes shipped so far this year – an increase of 8% on 2017 levels. Russian trade continues to dominate the change in rankings meanwhile, with close to 500,000 tonnes imported from this source in 2018, up 72% year on year. Fourth quarter contract prices were settled at $163-173/t c.fr, with the low end of the range representing US Gulf supply and the high end for tonnes ex-Middle East and the FSU.

Another key market for sulphur demand in the outlook is Morocco. The continued expansion of OCP's Jorf Lasfar processed phosphates hub led to a 10% rise in sulphur imports in January-August 2018 totalling 3.9 million tonnes. OCP has also increased imports of sulphuric acid – supporting acid tightness and pricing. Due to the absence of domestic sulphur supply in Morocco, any change in demand impacts sulphur trade. Middle East producers dominate trade, with over 60% of total imports from the region in 2018 to date. The UAE is the leading supplier, supplying around 1.7 million tonnes following by Saudi Arabia and Kuwait at 502,000 tonne and 146,000 tonnes respectively.

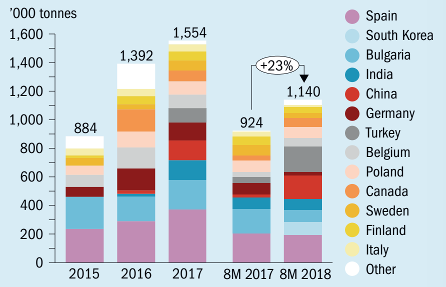
Over in NW Europe, fourth quarter contracts were reported settling at increases of $10-12/t, with the Benelux price pegged at $130-146/t. Tight supply has been a feature of the market through 2018 – with several factors contributing to the market balance. Disruption of gas based supply in Germany for several months led to reduced inventories. Refineries were also leaning to sweeter crudes, leading to reduced sulphur recovery. Demand from the industrial sector has been healthy in the region, supporting the uptick in pricing. Expectations are for the firm sentiment to remain going into the new year.

Fig. 1: **Month average spot sulphur prices, Jan 15 to Nov 18**



Source: Integer, ICIS

Fig. 2: **Moroccan sulphuric acid imports, 2015 to 2018**



Source: Integer, GTIS

Short-term dynamics in the market point to a price correction, with a floor in pricing likely to be found due to the continued tightness in the market. Buyer decisions in leading market China will have a significant impact on price direction.

SULPHURIC ACID

Sulphuric acid prices across major benchmarks have firmed further through the third quarter and look to remain robust in the coming months, to at least the first half of 2019. Supply side disruptions have underpinned sentiment for most of the year and healthy demand in key importing countries has supported the firm tone.

NW European export prices for spot acid hit the $80/t f.o.b. mark in September on the high end of the range, up $15/t from the start of the third quarter. Prices remained stable at $70-80/t f.o.b. through October. Overall, prices have surged by 167% since the start of 2018 – with unplanned outages in several regions taking its toll on spot availability during a period of healthy demand. The lack of availability has led to limited opportunities to test the price – but expectations are for firm stability through to the end of 2018. The tight supply situation has been highlighted by trade data – reflecting a drop in exports from several suppliers including Germany, Belgium and Spain.

Smelter outages in several parts of Asia have contributed to the run up in pricing, alongside demand side fundamentals. The Vedanta/Sterlite Tuticorin smelter in Tamil Nadu in India remains closed with ongoing uncertainty surrounding the potential for a restart. Sulphuric acid capacity at the copper facility is over 1 million tonnes – largely for the domestic market. Local buyers have found equilibrium through increased imports and increased sulphur burning. However, there has been an impact on some end users – leading to some reductions in downstream production as acid prices have become an issue for some consumers.

Contract negotiations in Chile for 2019 have been a major market focus through October, with the spot price range up at $122-130/t c.fr Mejillones in October. Some contracts were heard settled by mid-October but negotiations are expected to continue through November due to the gap in price ideas. Spot levels have been a key negotiating point for suppliers as well as expected tight supply through the first half 2018. There has been some discussion around the potential to change the contract structure from an annual fixed price to quarterly or on a six month basis. However the annual pricing format remains the preferred method for the time being.

Brazilian import demand has been below 2017 levels but above 2016 at 375,000 tonnes in the period to September – around 20% below the same period a year earlier. Elemental sulphur imports continue to trend above 2017 – indicating increased sulphur burning in the country. Spain, Belgium and Germany showed significant drops in acid trade – with exports from these countries dropping owing to tight supply. Buyers in Brazil were on the sidelines at the end of October, with most heard covered through to end December. On the pricing front, spot levels were assessed in the $110-117/t c.fr range at the end of October.

OCP's sulphuric acid procurement strategy remains a talking point in the market, with shipments to Morocco continuing to exceed 2017 levels. In January-August 2018 acid imports totalled 1.1 million tonnes, around 23% higher than a year earlier. While Spain is the leading supplier, Turkey has seen significant gains through the year and is the second largest supplier – shipping just under 180,000 tonnes so far. China is also now a major supplier to North Africa – in 2017, just 21,000 tonnes were shipped to Morocco. In the first eight months of the year the tally is 162,000 tonnes. The continued presence of Morocco in the import market remains a key factor for pricing and supports the firmer outlook in the early part of 2019. ■

Price indications

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

Cash equivalent	**May**	**June**	**July**	**August**	**September**
Sulphur, bulk ($/t)					
Adnoc monthly contract	125	136	139	140	152
China c.fr spot	152	157	162	175	190
Liquid sulphur ($/t)					
Tampa f.o.b. contract	113	113	121	121	121
NW Europe c.fr	117	117	n.a.	126	126
Sulphuric acid ($/t)					
US Gulf spot	100	100	110	110	110

Source: various

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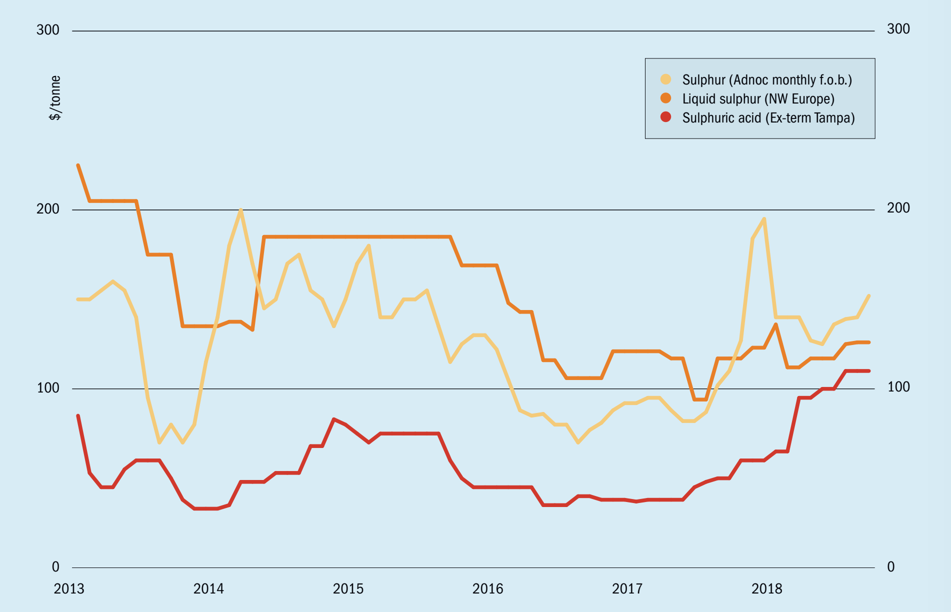
Market outlook

Historical price trends $/tonne



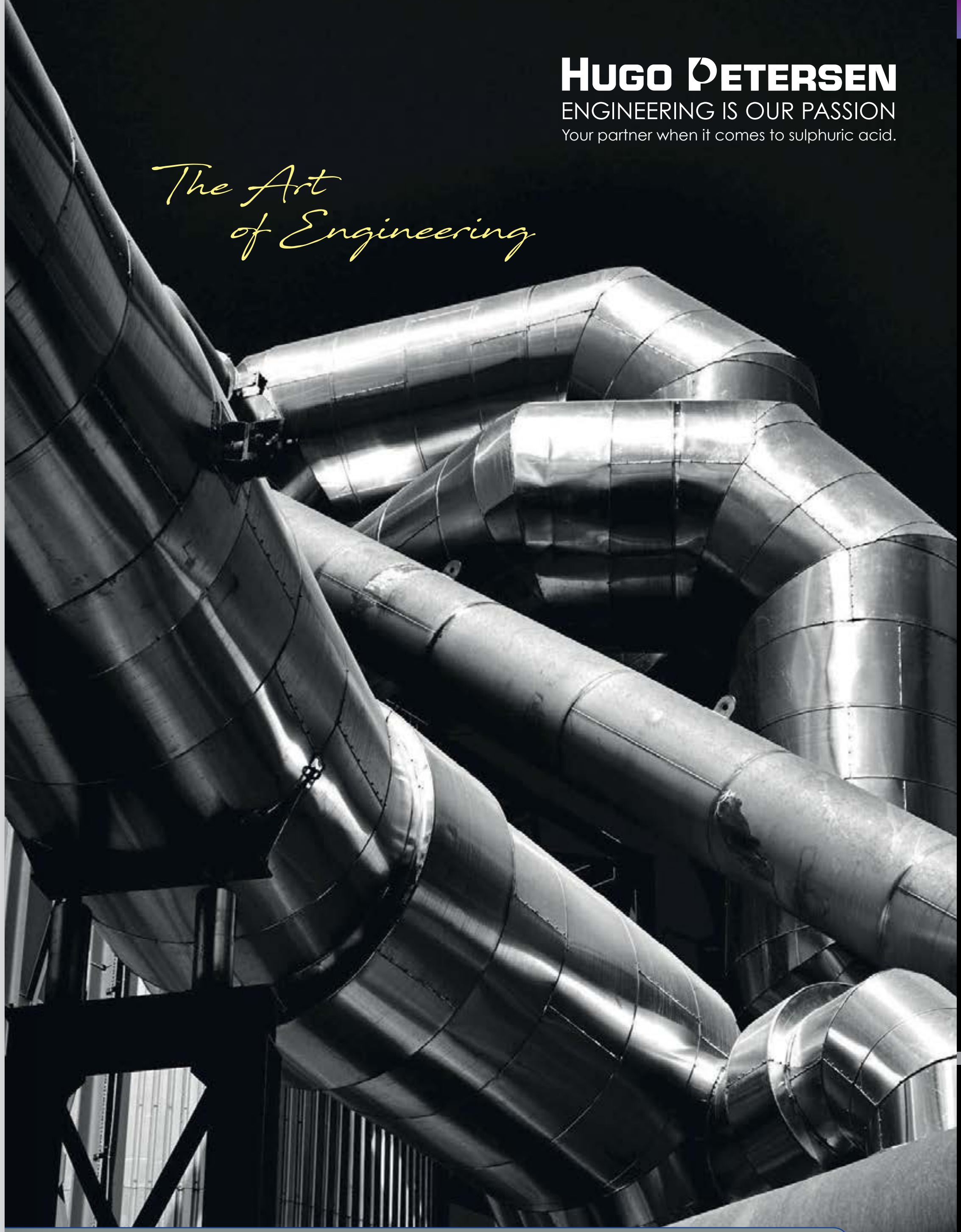
Source: BCInsight

SULPHUR

- Resistance from key buyers in China and India may underpin how long the price correction continues and the extent to which prices erode.
- Morocco's healthy demand for the processed phosphates sector is key for Middle Eastern trade, a market bull factor for the short term outlook.
- The addition of new sulphur capacity in China will be a significant market factor to monitor due to the influence of China on global trade and pricing. As the world's leading importer of sulphur any downward shifts in demand for imported volumes would lead to a shift in trade patterns and is a potential market bear – assuming production rises as planned.
- The IMO 2020 regulations continue to impact refinery feedstock choices and upgrades – in recent months increased preference for sweeter crudes has led to reduced sulphur availability. Some producers are increasing sulphur recovery meanwhile to meet low sulphur fuel requirements.
- **Outlook:** Sulphur prices are set to soften following the recent price run. Should buying interest wane further in major markets, prices may see further erosion. However, the tight supply situation due to outages, the preference for sweeter crudes at refineries as well as the approaching seasonal slowdown at major supply sources over the winter period will likely lead to the market reaching a floor and potential recovering. New supply sources from the Middle East and the FSU are market bears for the period beyond 2019.

SULPHURIC ACID

- China continues to ramp up its domestic production from smelters. Rising output will likely signal a reduced need for imports as well as the potential for increased exports. Both of these factors could lead to a softer market, particularly in Asia but the impact of new supply is unlikely to erode pricing before the first half of 2019 due to the tight global balance. Logistics remain a challenge for some smelter producers in China.
- Trade from South Korea is expected to shift in 2019 with reduced volumes planned to traditional market China.
- Glencore's PASAR Philippines smelter may see some improvement in supply in 2019 but continued planned maintenances may still lead to reduced availability of tonnes below capacity rates.
- European turnarounds for 2019 include shutdowns at Aurubis' plants in Germany and Bulgaria which are estimated to lead to a loss of 170,000 tonnes of acid.
- **Outlook:** Prices are unlikely to trend downwards in the short term due to supply side disruptions expected through the first half of 2019. In Europe, supply has been tightening on the back of domestic consumption rates, maintenance turnarounds and firm demand in key importing markets. The uncertainty surrounding the Sterlite Tuticorin smelter in India is also a supportive factor as it is unclear if or when the plant would be restarted. Demand in Chile is set to remain firm in 2019 – further buoying trade as the mark. ■



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Sulphur Industry News

UNITED ARAB EMIRATES

New sulphur pipeline "on track"

Adnoc Sour Gas, previously known as Al Hosn Gas, says that work on a new sulphur pipeline for the Shah field remains on track. In a statement, the company said that engineering, procurement, construction, and commissioning (EPCC) works on the new pipeline – being carried out by German firm MMEC Mannesmann – will be completed in 2019. The new pipeline will carry liquid sulphur from the main processing plant 11 km away to the sulphur forming facility, where the sulphur will be granulated, stockpiled, and transported by rail to the export terminal at Adnoc's Ruwais downstream hub. Adnoc Sour Gas, which accounts for 10% of gas production in the UAE, is a 60:40 venture between Adnoc and Occidental Petroleum. The company, which currently produces 1 billion scf/d of sales gas, roughly half of it at Shah, is aiming to expand production at the Shah sour gas plant by 50%.

It will also continue the company's expansion to become one of the world's largest producers of sulphur. Adnoc says that it currently produces 9-10,000 t/d (3-3.5 million t/a) of sulphur at Shah, which took Abu Dhabi's sulphur production to 6 million t/a when the facility opened in 2016. ■

New remelter installed at Shah

Adnoc Sour Gas says that it has also recently successfully started up a sulphur re-melt unit at its Shah sulphur granulation facility to maximise sulphur recovery that is otherwise lose during transport operations. The company says that up to two tonnes per day is lost during the transport of granulated sulphur via conveyors to stockpiles or trains. Previously, due to sand and rock contaminants, the lost sulphur had to be disposed of off-site. With the commissioning of the re-melter Adnoc is able to recycle the sulphur and add it back into the daily production quota.

Omar Obaid Al Nasri, Adnoc Sour Gas Acting CEO said: "Thinking differently to create a solution which reduced our environmental impact, creates substantial savings and revenue over the life of the project and incorporates innovation, is at the heart of everything we strive to do at Adnoc. It underlines our commitment to making our operations more efficient and performance driven as we accelerate delivery of Adnoc's 2030 growth strategy."

SRU replacement project

China's Wison Engineering Services has won an $80 million engineering, procurement, construction, and commissioning (EPCC) contract for the Abu Dhabi Oil Refining Company's (Takreer) sulphur recovery unit replacement project. Wison will also carry out design, testing, and start-up work, the company said in a stock exchange filing. Takreer is a wholly owned subsidiary of the Abu Dhabi National Oil Company (Adnoc). Wison says that work will be completed by 2021.

Commenting on the contract, Abdulla Ateya Al Messabi, manager of Adnoc's refining and petrochemicals business unit, said: "The contract has been awarded after a rigorous and robust tendering process. "Wison Energy Engineering was selected for its track record in delivering related projects. It will allow us to enhance the value from our existing resources and assets by increasing the efficiency of our operations and reducing operational and maintenance costs."

Adnoc forms partnership with Baker-Hughes

Adnoc has signed a strategic partnership agreement with US oilfield services company Baker Hughes – part of the GE Group – to support the growth and development of Adnoc subsidiary Adnoc Drilling into an integrated drilling and well construction provider. Baker Hughes will provide ongoing technology, software, equipment and training support. As part of the agreement, Baker-Hughes will also take a 5% stake in Adnoc Drilling. The transaction values Adnoc Drilling at approximately $11 billion. This is the first time that Adnoc has allowed an international strategic partner to acquire a direct equity stake in one of its existing services businesses. Adnoc Drilling is the largest drilling company in the Middle East. The two companies will set up an advisory board with representation from both companies to oversee the implementation and ongoing operations, and Baker Hughes will be represented at board level on Adnoc Drilling. Adnoc is aiming to increase its conventional drilling activity by 40% by 2025 and substantially ramp up the number of its unconventional wells, in line with its 2030 growth strategy. It also aims to reduce drilling time by 30% by the end of 2019.

Concessions signed on ultra-sour offshore fields

The Abu Dhabi National Oil Company (Adnoc) has signed the first of a series of concession agreements with Italy's multinational oil and gas company, Eni, awarding it a 25% stake in its major offshore ultra-sour gas project. The Ghasha concession consists of the Hail, Ghasha, Dalma and other offshore fields. Eni will contribute 25% of the development cost of the multi-billion US dollar project. The concession, which has a term of 40 years, was signed by Sultan Ahmed Al Jaber, UAE Minister of State and Adnoc Group CEO, and Claudio Descalzi, CEO of Eni. Adnoc says that it is still in discussion with further potential partners for the remaining 15% of the available 40% stake in the Ghasha concession, earmarked for foreign oil and gas companies. The announcement follows the Supreme Petroleum Council's approval of Adnoc's new gas strategy, targeted to maximise value from Abu Dhabi's available gas reserves, as the UAE moves towards gas self-sufficiency and aims to transition from a net importer of gas to a net gas exporter.

The Hail, Ghasha and Dalma fields are part of the Arab basin, which is estimated to hold several trillion of standard cubic feet of recoverable gas. The project is expected to produce more than 1.5 bcf/d of gas when it comes on stream around 2025, sufficient to feed power plants providing electricity to more than two million homes. It will also produce over 120,000 bbl/d of oil and high value condensate, and of course significant volumes of sulphur. Adnoc says it will draw on experienced gained with the Shah onshore sour gas field, due to be expanded in a few years' time, as well as applying state of the art 'smart' technologies and leveraging digital innovations to ensure remote access to all key activities across the project's natural and artificial islands, platforms and wellhead towers, operated from a single control centre in Al Manayif, reducing human exposure to the operations.

Sultan Al Jaber said: "In combination with Adnoc's leading experience in ultra-sour gas, Eni's field development experience supports the accelerated delivery of gas from the Hail, Ghasha and Dalma fields. At the same time, it will enable the further optimisation of costs and ensure we extract the maximum value from our gas resources, as we continue to partner with those who share our values and contribute to our growth strategy."

Claudio Descalzi, CEO of Eni and Sultan Ahmed Al Jaber, Adnoc Group CEO, at the signing ceremony.

BAHRAIN

Site preparation complete on Bapco upgrade

The Bahrain-based engineering and infrastructure services company Downtown Group says that it has completed Package A (site preparation work), of the Bapco Modernisation Programme. It forms part of a several billion dollar engineering, procurement, construction and commissioning (EPCC) contract for the modernisation programme awarded to a consortium led by TechnipFMC which will take the Bharain Petroleum Company (Bapco) refinery at Sitra from a capacity of 267,000 bbl/d to 360,000 bbl/d, as well as improving energy efficiency and environmental performance and lead to greater value being captured from the bottom of the barrel. The modernisation programme includes a residue hydrocracking unit, hydrocracker unit, hydrodesulphurisation unit, crude distillation unit, vacuum distillation unit, saturated gas plant, hydrogen production unit and hydrogen recovery unit, as well as improvements to the sulphur recovery unit, tail gas treatment unit, sour water stripper, amine recovery, acid gas removal unit, sulphur forming plant and sulphur handling facilities.

CHINA

Nantong port ends imports of solid sulphur

CRU reports that the Chinese port of Nantong on the Yangtse River has ended all imports of solid sulphur from October 2018, and has begun the process of selling off all remaining sulphur stocks, as part of an environmental drive to limit pollution to the residential population of Nantong. Bulk crushed lump sulphur imports have been restricted to all Yangtze river ports since Q2 2018 with the product now only accepted in jumbo bags. The processing of molten sulphur to solid at sites along the Yangtze is also restricted. The move reportedly follows inspections carried out in 2016 by the Ministry of Ecology & Environment which identified that sulphur storage had caused pollution when waste water was pumped directly into the river. The port's water discharge is located only 1.8 km from Nantong city's main water intake.

More sulphur from refinery upgrade

PetroChina's Daqing Petrochemical facility in northeastern Heilongjiang has begun an upgrading project to provide feedstock for its 1.2 million t/a ethylene plant, while cutting gasoil output. The project includes upgrades to the existing 3.5 million t/a crude distillation unit, 1.2 million t/a hydrocracker and 1.2 million t/a gasoil hydrogenation units, as well as constructing new units for the production of 90,000 t/a of MTBE, a 220,000 t/a alkylation unit, a 1.2 million t/a continuous reformer unit, a 2 million t/a fluid catalytic cracking unit, a 600,000 t/a gas fractionator, a 500,000 t/a gasoline desulfuriser and two 20,000 t/a sulphur recovery units.

MALAYSIA

Refinery to move to Euro-V diesel by 2020

ABB has won an order from Hyundai Engineering to modify existing and install new electrical systems and electrical network monitoring and control system at Malaysia's biggest crude oil refinery at Melaka, in the southern region of the Malay Peninsula. Hyundai was appointed earlier this year by the Malaysian Refining Company as EPC contractor for the upgrade to existing oil refining facilities to meet a Euro-5 fuel sulphur standard of <10mg per kg to improve air quality. The refinery has been operating since 1994 and houses two refinery trains with a total capacity of 270,000 barrels per day.

ARGENTINA

New hydrotreater for YPF

Argentine oil and gas company YPF SA has contracted DuPont Clean Technologies to license and provide basic engineering of a new *IsoTherming*® diesel hydrotreater. The hydrotreater will be installed at the YPF Plaza Huincul refinery in Neuquen Province, Patagonia. The refinery produces gasoline, diesel, jet fuels and methanol. YPF is looking to increase hydrocarbon production and comply with new low sulphur fuel specifications by 2022. *IsoTherming*® uses a novel liquid phase reactor which DuPont says offers lower capital and operating costs compared to conventional hydroprocessing technologies.

UNITED KINGDOM

ExxonMobil to upgrade Fawley refinery

ExxonMobil says that it is planning to upgrade its Fawley refinery. The investment – the company's largest in the UK in 30 years – will see a spend of $650 million. The refinery, at Southampton on the UK's south coast, is the largest in the UK, and processes 270,000 bbl/d of crude, 20% of the country's refining capacity. The upgrade includes oil processing

SULPHUR
ISSUE 379
NOVEMBER-DECEMBER 2019

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units, allowing it to produce higher quality diesel, and a new hydrotreater, supported by a new hydrogen plant. The aim is to allow the site to process a wider selection of crudes, especially heavier, sourer barrels, into ultra-low sulphur diesel, reducing the UK's need for diesel imports. A final investment decision is expected in 2019 but work has already begun on clearing the site for the planned expansion.

Simon Downing, Fawley Refinery manager, said: "If this project is approved, it would be a major investment in the site amounting to hundreds of millions of pounds, and a bold statement of confidence in Fawley and its ability to produce high quality fuels for the UK economy."

CANADA

Full scale demonstration of new solvent

ExxonMobil Catalysts and BASF Corp are conducting a full scale commercial demonstration of a new gas treating solvent at Imperial Oil's Sarnia refinery, Ontario. The companies say that they jointly developed the new amine-based solvent to meet more stringent sulphur emission standards with greater efficiency. The solvent improves the selective removal of hydrogen sulphide and minimises co-absorption of CO_2 from gas streams. ExxonMobil and BASF claim that the highly selective properties of the solvent allow refiners and gas processors to increase capacity and lower operating costs in existing equipment. Pilot plant testing has demonstrated superior performance characteristics over conventional methyldiethanolamine (MDEA) formulations and even *FLEXSORB SE/SE Plus* solvents.

"The new solvent technology will provide immediate benefits to ExxonMobil facilities and to our gas treating customers," said Dan Moore, president of ExxonMobil Catalysts and Licensing. "This commercial demonstration is to tangibly show the new level of performance."

"Thoroughly tested at BASF's dedicated pilot plant in Ludwigshafen, Germany, the solvent showed improved H_2S selectivity and lower energy consumption than other selective solvents," said Andreas Northemann, vice president of gas treatment at BASF.

THAILAND

Clean fuel project for Sriracha refinery

Thai Oil PLC, part of the Petroleum Authority of Thailand (PTT), has awarded a $4 billion contract to a consortium of Saipem, Petrofac, and Samsung for the company's new Clean Fuel Project at its 275,000 bbl/d refinery at Sriracha. The contract covers engineering, procurement, construction and start-up for new units and the upgrading of existing units. Refinery capacity will increase to 400,000 bbl/d with the addition of a new 220,000 bbl/d crude distillation unit and the retirement of two older, smaller CDUs. New refinery components include a vacuum gas oil hydrocracker, a residue hydrocracker, a hydrogen plant, a naphtha hydrotreater, a diesel hydrodesulphurisation unit, and a new sulphur recovery unit. It will also mean that the refinery is no longer completely dependent on light crude, but will be able to handle up to 50% heavy, sour crudes once the project is complete.

NETHERLANDS

Shipping fuel upgrade put on hold

Global energy trader Gunvor Group says that it has put on hold plans to upgrade its Rotterdam refinery to meet new MARPOL rules on shipping fuel quality. The International Maritime Organisation (IMO) will ban ships using fuel with a sulphur content higher than 0.5% from 1st January 2020 unless a vessel has scrubbers installed to clean up its sulphur emissions. In a press statement Gunvor said that its plans to install a delayed coker to the 88,000 bbl/d refinery to be able to supply the new market for low sulphur marine fuels that will be created have been deferred because: "the price environment and other relevant economics have changed considerably since Gunvor first began exploring the concept a year ago." Gunvor bought the refinery from Kuwait Petroleum International in 2016. Last year, it sold its stake in crude oil storage at the nearby Maasvlakte Olie Terminal to Saudi Aramco Overseas Co.

UNITED STATES

Start-up for hydroprocessor

DuPont says it has successfully started up its first *IsoTherming®* hydroprocessing application to treat diesel from a transmix processing facility. Transmix is a mixture of refined products that forms when transported in pipelines, typically a combination of gasoline, diesel and/or jet fuel. The hydrotreater, at the Gladieux processing facility in Huntington, Indiana, has successfully completed its performance test, certifying that it is exceeding performance guarantees and producing 5,000 bbl/d of ultra-low sulphur diesel (ULSD) containing <10 ppmw sulphur. Gladieux said that capital cost advantages, as well as comparatively lower utility consumption, were key drivers for its selection of the technology for this project, which has the global IMO marine fuel sulphur cap in mind.

ECUADOR

Tender for new SRU as part of refinery upgrade

Petroecuador will issue a tender next year for the construction and operation of two new processing units at its state-run Esmeraldas refinery, the company says, including a sulphur recovery unit. However, the work will have to wait until maintenance work at the refinery has been completed. The company completed a $2.2 billion overhaul of the 110,000 bbl/d facility in 2017 as part of a bid to reduce the country's need for imported fuel, but since then has suffered operational issues. A 60-day shutdown is planned for March 2019 during which time repair and maintenance work will be conducted on the fluid catalytic cracker and hydrodesulfurisation unit. Once this is complete, Petroecuador says that it will award two 20-year contracts to construct new sulphur and fuel processing units under a build-operate-transfer model. ■

CORRECTION

Further to the news item which appeared in our July/August issue (New acid plant 50% complete, *Sulphur* 377, page 15), we would like to clarify that the Teck Trail Operations' No. 2 sulphuric acid plant project that is currently under construction is not designed by Amec Foster Wheeler (now owned by Wood Group). Chemetics received the contract from Teck Metals Ltd. to provide complete design of the sulphuric acid plant, plus supply of all equipment and majority of materials, including Jacobs' proprietary Chemetics equipment throughout. AmecFW (Wood) is providing detailed design and construction services on the project, and Chemetics are working closely with Teck and AmecFW on the wraparound scope in support of the sulphuric acid plant project.

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Sulphuric Acid News

INDONESIA

Tsingshan to invest in HPAL nickel production

Chinese battery firm and Contemporary Amperex Technology Ltd and battery recycler and materials supplier GEM Co Ltd will join a consortium including Chinese metals giant Tsingshan Holding Group to build a 50,000 t/a high pressure acid leach (HPAL) nickel plant at Weda Bay in Indonesia, the companies have announced. Other companies said to be involved include Japan's Hanwa and the Indonesia PT Bintangdelapan Group. The plant, priced at $700 million by the partners, will produce high purity nickel for an expected surge in demand for the metal to produce batteries for the electric vehicle sector. The project will also produce 4,000 t/a of cobalt.

There has been some scepticism around the announcement – CRU has pointed out that $700 million represents only $14,000 per tonne of installed nickel capacity, less than a quarter of the cost of previous HPAL projects, which have suffered from technical issues and cost overruns. Nevertheless, Tisngshan has a history of disruption in the nickel industry, with its adoption of low cost nickel pig iron (NPI) production to feed stainless steel manufacture, leading to an 80% slump in nickel prices between 2007 and 2008. The general feeling in the industry seems to be: if anyone can do it, Tsingshan can.

The company has also set a hugely ambitious timescale for the project, aiming to have it up and running in just a year – previous HPAL projects have taken 5-10 years to come to fruition. It is one part of a potential renaissance in HPAL nickel production, which had been assumed to be too costly to cope with current nickel prices, with Japan's Sumitomo also looking towards new HPAL production in Indonesia – the company already operates HPAL capacity in the Philippines. ■

CANADA

Lawsuit over sulphuric acid spills

The Insurance Corp. of British Columbia (ICBC) is suing Teck Metals, the British Columbia provincial government and a variety of other defendants following a series of sulphuric acid spills on public roads led to 3,900 claims to ICBC for damage to vehicles. The notice of civil claim was filed in the British Columbian Supreme Court and names Teck Metals Ltd., Teck Resources Ltd., International Raw Materials Ltd., Westcan Bulk Transport Ltd., the City of Trail, and even the Queen via the British Columbia Minister of Transportation and Infrastructure, Minister of Environment and Climate Change Strategy, as well as the drivers of the tanker trucks as defendants.

The lawsuit alleges that Teck manufactures and stores "large volumes" of sulphuric acid at its facility near the city of Trail, which is bought by International Raw Materials and transported in tankers by Westcan Bulk Transport, and that between April and September 2018, there were four separate spill incidents. It further claims that the highway and adjoining roadways were not closed promptly, or at all, while the spills caused the highway to be "unsafe and unsuitable for public use," and that vehicles that drove through the spills suffered "serious and extensive damage."

In response, Teck has said that clean-up of the spills was done in accordance with Transportation of Dangerous Goods standards, including: using lime to neutralise visible acid, which was then collected and taken to Teck for disposal. The roadway was also flushed with thousands of litres of water and pH tests to confirm the acid had been neutralised were conducted. The company further argues that in areas where there was any potential for acid to enter drains prior to clean-up commencing, seal mats were used to cover the drains and later removed prior to street flushing.

Teck operates 460,000 t/a of metallurgical acid capacity at the site in Trail, British Columbia.

SAUDI ARABIA

Ma'aden awards ammonia contract for Phosphate 3 complex

The Saudi Arabian Mining Company (Ma'aden) has awarded South Korea's Daelim a $892 million engineering, procurement and construction (EPC) contract to build the first plant in the company's third large-scale phosphate complex (Phosphate 3). The contract is for a 1.1 million t/a ammonia plant which will join the others at the coastal Ras al Khair processing facility where the company produces diammonium phosphate (DAP). The new ammonia plant is due to be completed at the end of 2021. The phosphate side of the mega-project is likely to begin operations in 2023 according to Ma'aden.

The Phosphate 3 expansion will ultimately take Ma'aden's processed phosphate capacity from 6 million t/a to 9 million t/a, making the company the world's third largest phosphate producer and second largest exporter after Morocco's OCP. The company currently mines and beneficiates almost 12 million t/a of phosphate rock via its subsidiary the Ma'aden Phosphate Company (MPC) at Al Jalamid in northern Saudi Arabia. In a recent press statement, chief executive officer Darren Davis said that the company is also "actively looking" for overseas investments.

WORLD

Another increase in catalyst prices

DuPont Clean Technologies and Haldor Topsoe have both announced further increases in sulphuric acid catalyst prices. DuPont said that global prices for its MECS sulphuric acid catalysts would increase by $0.40/litre across the board, effective immediately, while Haldor Topsoe said that it would increase the price of the company's VK sulfuric acid catalysts by €0.3 per litre.

SPAIN

OCP buys into Fertinagro

Morocco's OCP Group has taken a 20% stake in Spanish plant nutrition company Fertinagro Biotech SL, for an undisclosed sum. As part of the transaction, Fertinagro and OCP have signed an intellectual property and know-how license agreement as well as a co-development agreement. OCP says that it is aiming to "boost innovation and offer customised fertility solutions to meet farmers' specific needs around the world" as part of a strategy focusing on innovation and product customisation.

"The strategic partnership we concluded with Fertinagro Biotech is a new step towards achieving our global growth strategy focusing on creating innovative, customised plant nutrition solutions adapted to crops and soils, to address the specific needs of farmers around the world. Furthermore, this alliance is intended to deliver more opportunities ahead as we grow together leveraging on both companies' complementary strength and capabilities," said chairman and chief executive officer of OCP Group, Mostafa Terrab.

Fertinagro has a total capacity of 2 million t/a at 22 manufacturing sites and logistical centres in Spain and France and sells into 60 countries worldwide.

RUSSIA

More acid rail wagons for UMMC

The Ural Mining Metallurgical Co (UMMC) has awarded United Wagon Co's (UWC) TikhvinChemMash plant a contract to supply a total of 73 sulphuric acid tank wagons by the end of January 2019. Seventeen of the rail tank wagons will be destined for UMMC's Sredneuralsk copper smelter, a further 30 will go to the Mednogorsk Copper & Sulphur Plant, and the Chelyabinsk zinc plant will take 26, taking the total number of acid wagons in the UMMC fleet to more than 100.

The Type 15-9545 tank wagons, designed by UWC's All-Union Research & Development Centre for Transportation Technology have 25 tonne axleload bogies and offer a capacity of 44 m^3 or 77 tonnes, compared to 39 m^3 and up to 69 tonnes for older equivalents. UWC says that the tank shape facilitates full drainage, and the gaskets are made from high molecular weight polyethylene which is more resistant to aggressive acids than the wood used on older vehicles. The hatches are fitted with fluoroplastic sealant, and are equipped with two nozzles for loading sulphuric acid and for the removal of sulphur dioxide gas via a flexible metal sleeve at depot degassing installations. The wagons are designed for a life of 18 years with maintenance intervals of 1,000,000 km or eight years.

EGYPT

First phosphate project to be operational soon

Speaking to local media, Sherif El-Gabaly, chair of the Chamber of Chemical Industries at the Federation of Egyptian Industries (FEI), said that the first of the country's two new major phosphate projects should be up and running in the next few months. The Ain Sokhna Phosphate Fertiliser Complex is under construction for the El Nasr Company for Intermediate Chemicals. It comprises two sulphuric acid units with a production capacity of 570,000 t/a each (1.25 million t/a total); two merchant grade phosphoric acid production units each with a capacity of 180,000 t/a; two 100,000 t/a purified phosphoric acid plants; 225,000 t/a of triple superphosphate production, and 180,000 t/a of mono- and di-ammonium phosphate capacity.

Meanwhile, work is continuing on the $800 million Waphco project at Abu Tartour on the Red Sea coast. Phosphate Misr, which operates the Abu Tartour phosphate mine, is in a joint development with the Abu Qir Fertilisers Company to build new phosphoric acid capacity, along with Al Ahly Capital Holding Company, state energy firm ENPPI, Petrojet and East Gas. The first phase of the project will include 250,000 t/a of wet process merchant grade phosphoric acid production and 750,000 t/a of sulphuric acid capacity. The second phase will include a duplicate of these plants plus a 330,000 t/a ammonia plant, and 525,000 t/a of single and triple superphosphate and complex phosphate fertilizer capacity. Fluor was awarded the FEED contract for the first phase in March this year.

MOROCCO

OCP uses Sulfacid process to reduce emissions

OCP says that it has begun implementation of the *Sulfacid* process in two sulphuric acid plants at its huge Jorf Lasfar phosphate complex at a cost of $60 million. A similar *Sulfacid* upgrade is also under construction at the company's Safi site. The process reduces process sulphur dioxide emissions from the contact unit by 98% from roughly 600 ppm to less than 15ppm by incorporating a supplementary gas scrubbing system. The raw gas to be treated flows through an activated carbon catalyst fixed bed inside the reactor. The SO_2 is converted to sulfuric acid by wet catalysis in the presence of oxygen and water, and the recovered acid is fed back into the process. The process has been widely used since the 1960s in metallurgical and chemical processes, but OCP claims that this is a first for sulphur-burning acid plants.

CHILE

Chuquicamata smelter down for emissions upgrade

Codelco, the world's largest copper producer, says that operations at two of its four smelters will be suspended for several weeks as it performs work to comply with tighter emissions legislation which will come into force in mid-December. Smelters at the Chuquicamata and Salvador mines will be halted for 75 days and 45 days, respectively, from December 13th when the new standards become enforceable. The smelters will take their annual maintenance shutdowns at this time as well, according to Codelco, which has invested $2.1 billion to adapt to new standards that require smelters to capture 95% of emissions. The upgrade at Chuquicamata includes two new sulphuric acid plants, a drying system and gas treatment system, which are due to be operational by the end of February, when capacity will increase to 2,400 t/d of copper. The two acid plants are designed by MECS and built by SNC Lavalin and each has a capacity of 2,050 t/d of acid (1.35 million t/a total). These new plants will replace those currently in operation at the facility, which have a capacity of 600,000 t/a of acid.

ZAMBIA

Chambishi smelter rail connection completed

At a commissioning ceremony, Zambia's Transport and Communications minister Brian Mushimba officially opened the Zambia Railway (ZRL) spur connecting the Chambishi copper smelter to the ZRL main line. The rail connection project has been a joint investment between ZRL and the Chambishi Copper Company and will take most of the output of the plant, both copper, copper concentrate and sulphuric acid, reducing congestion on the roads and the potential for accident. However, ZRL is reportedly still short of rolling stock as part of the government's planned upgrade to its capacity; the SI-7 improvement plan, which requires 30% of heavy freight traffic to be moved by rail instead of road, still requires the company to purchase another 34 locomotives and 1,800 wagons to meet its target. ■

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People

At Cefic's annual General Assembly, **Daniele Ferrari**, CEO of Versalis, was elected the new president of Cefic, effective immediately. He succeeds **Hariolf Kottmann**, chairman of the board of Clariant, who had held the post since October 2016. As well as being CEO of Versalis, Ferrari is chairman of Matrìca, a joint venture focusing on renewable chemistry. A thirty-year career in the chemical industry has seen him take on managerial assignments in Italy, the UK, Belgium and the US, working for ICI and Huntsman. Since June 2017 he has also been President of PlasticsEurope, a pan-European association representing plastics manufacturers. He will combine the role of President of Cefic and PlasticsEurope for a month before handing over to his successor in PlasticsEurope (yet to be appointed). He is also vice-president for Europe of the Italian Chemical Association (Federchimica) and serves as a non-executive director of Venator Materials and Huntsman Corporation.

Marco Mensink, Cefic's Director General said: "I am pleased to welcome Daniele as our new President. With the challenges of Brexit, upcoming EU elections and transition to a more low-carbon economy, the industry needs a strong and capable leader like Daniele. At the same time we thank Hariolf Kottmann for his outstanding leadership over the past two years. Under his presidency we restructured Cefic, signed a Memorandum of Understanding with the European Chemicals Agency (ECHA) and secured China's membership in the International Council of Chemical Associations (ICCA)."


Lisa Davies

Daniele Ferrari, Cefic's new President said: "the EU chemical industry is already playing a key role in addressing the world's biggest challenges by developing technologies to mitigate climate change, use resources more efficiently and facilitate recycling. My ambition is to promote a European environment in which the chemical industry can grow and support the transition to a sustainable society, towards the circular economic model. At the same time, we will continue to help the European chemical industry to attract investments and thrive at a global level. Chemistry will help us move forward towards a stronger European economy."

Lisa Davies, project engineering manager at Fluor, was named a Global Energy Awards Rising Star finalist by S&P Global Platts. Winners will be announced at the S&P Global Platts Global Energy Awards banquet on December 6th, 2018, in New York. Davies represents Fluor's Power business line, with a focus on power plant waste processing and storage. She is currently serving as the project engineering manager for Fluor supporting Ontario Power Generation's nuclear waste management facilities. The Rising Star award recognizes leaders who have made remarkable strides in their current role, impacting their industry.

"I am proud to say that this is the second year in a row that Fluor has had a finalist for the esteemed Rising Star award," said Simon Nottingham, president of Fluor's Power business. "Lisa is a hands-on leader who is ardent and steadfast in her pursuit to create an enduring positive impact in the nuclear power industry. We look forward to supporting her in New York when the winners are announced."

At the 2018 Hydrocarbon Processing awards in Houston, Texas, DuPont Clean Technologies won "Best Refining Technology" for its *ConvEx*℠ HF Alkylation Conversion Technology. Accepting the award for DuPont was **Shane Presley**, technical service and development manager. Shane and **Jason Nunez**, senior technical service engineer, were instrumental in developing the technology.

Eli Ben-Shoshan, global business leader, DuPont Clean Technologies said, "While we're thrilled to win this prestigious award, we're even more excited to bring this cost-effective HF alkylation conversion and expansion technology to the market." ■

Calendar 2018/19

NOVEMBER

28-30

European Refining Technology Conference,
CANNES, France
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Senior Conference Producer & Project
Manager, World Refining Association
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Email: sofia.barros@wraconferences.com

FEBRUARY 2019

4-5

SulGas Gas Treating & Sulphur Recovery
Conference, MUMBAI, India
Contact: Conference Communications Office,
c/o Three Ten Initiative Technologies LLP,
12-1-16 Waltair Main Road,
Visakhapatnam, Andhra Pradesh, India.
Web: www.sulgasconference.com

25-28

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

MARCH

11-12

Sulphur and Sulphuric Acid Conference,
SWAKPOMUND, Namibia
Contact: Camielah Jardine,
Head of Conference, South African Institute
of Mining and Metallurgy
Tel: +27 (011) 834-1273/7
Fax: +27 (011) 833-8156
Email: camielah@saimm.co.za

17-19

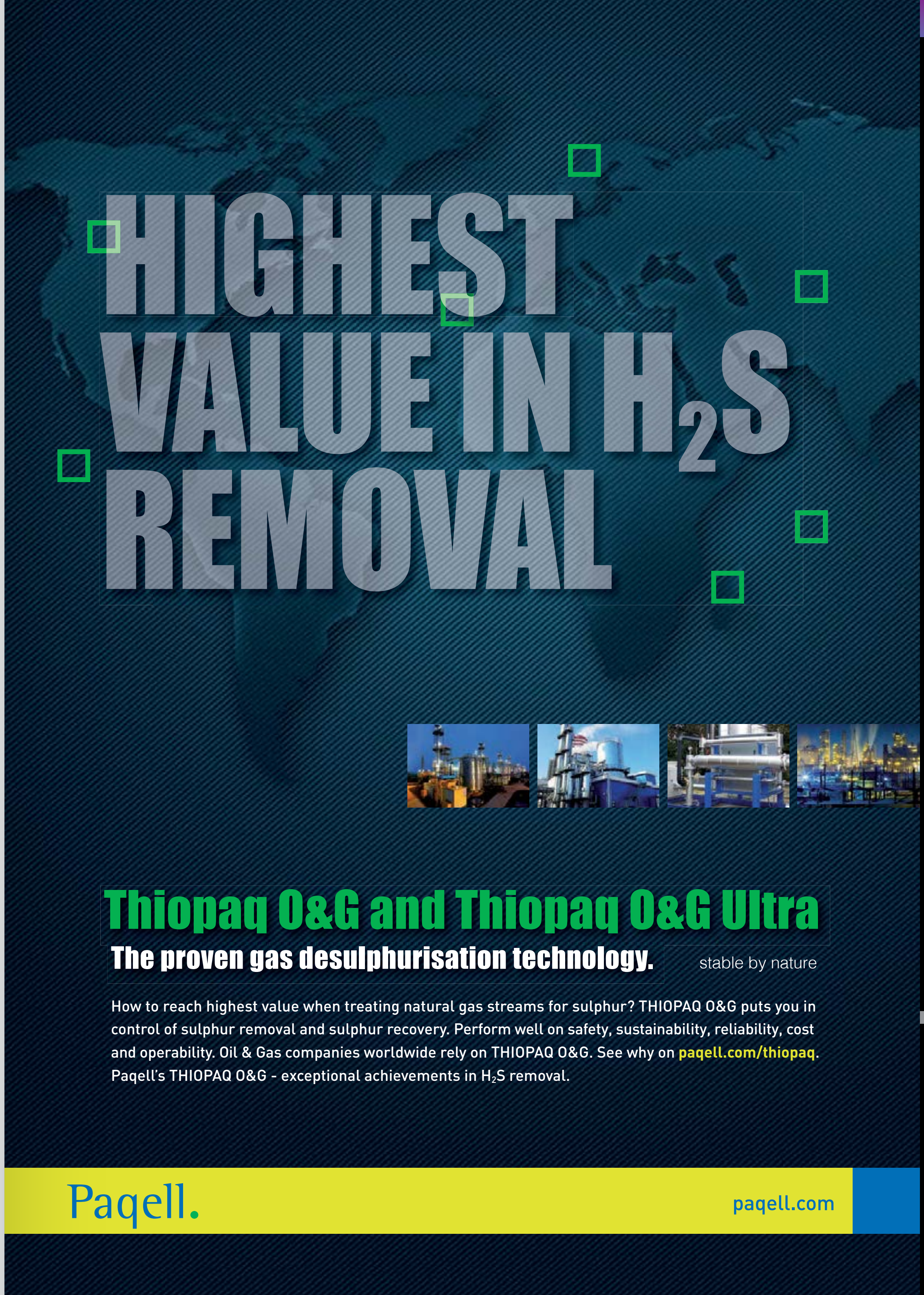
AFPM Annual Meeting,
SAN ANTONIO, Texas, USA
Contact: American Fuel and Petrochemical
Manufacturers (AFPM)
1667 K Street, NW, Suite 700,
Washington, DC 20006, USA.
Tel: +1 202 457 0480
Email: meetings@afpm.org
Web: www.afpm.org

25-27

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

25-28

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



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Oil sands mining at Fort Hills, Alberta.

PHOTO: SUNCOR

The future of Canadian sulphur production

Although Canada is no longer the largest sulphur exporter in the world, it is still among the largest. But declining recovery from sour gas has not been matched by increases from sour gas processing, while Canadian producers face stiff competition from Middle Eastern sulphur producers like Adnoc.

Canada was the largest sulphur exporter in the world from the early 1970s until just a couple of years ago. During its heyday Canadian exports represented 40% of all traded sulphur, and the Canadian sulphur industry came to define the world of sulphur, from its sour gas operations, recovery and forming technologies to the SUDIC standards which still predominate and the research effort provided by Alberta Sulphur Research Ltd. But when the Shah project came on-stream in Abu Dhabi in 2015, it took the UAE's sulphur production capacity to almost 6 million t/a, and in 2016 Canada finally lost its place as the world's largest exporter.

Exports from the Middle East have been steadily rising from countries such as Qatar and Iran, and from Kazakhstan in central Asia, while Canadian sulphur output has fallen, at the same time that US demand for Canadian sulphur has also fallen as the phosphate industry there contracts, while the start-up of Mosaic's re-melter in Florida has also opened up other options for the US potash industry to import dry bulk sulphur from the Middle East or elsewhere. With the sulphur producing centres of northern Alberta a long way from the export port of Vancouver, and hence burdened by relatively high logistics costs, can Canada keep its place among the world's major sulphur traders?

Sulphur output

In terms of elemental sulphur, there are broadly three sources of elemental sulphur in Canada. Still the largest is the legacy of sour gas processing in Alberta and British Columbia, although production continues to slowly decline. Next comes processing and upgrading of oil sands bitumen, again mostly based in Alberta. Finally there is some conventional oil refining, in the east of the country, which generates sulphur. If one looks at sulphur in all forms, sulphuric acid produced from metal smelting could also be added to the total.

Sour gas

Almost all of Canada's natural gas production comes from the Western Canadian Sedimentary Basin (WCSB), which extends from Saskatchewan across northern Alberta and British Columbia and up into the Northwest Territories. The first commercial gas field began operations in Alberta in 1901, but the highly sour nature of many of the fields limited exploitation at first until a process for scrubbing H2S from the gas was developed in the 1920s. At Turner Valley the hydrogen sulphide was absorbed using soda ash and then flared, allowing commercial gas production, and western Canada came to become one of the pioneers of sour gas extraction and processing.

The first sulphur production came from Shell's Jumping Pound field, discovered in 1944, with sulphur production beginning in 1951. As more sulphuric acid was required for metal processing and other industries, so there was an incentive to recover more and more sulphur. Canada's sulphur industry grew to become one of the world's largest sources of sulphur, producing 7 million t/a of elemental sulphur throughout the 1970s. By now sulphur was a major export commodity, taken by rail to the coast at Vancouver, and Canada came to represent 40% of the global sulphur market. Moves to end flaring of sour gas boosted sulphur recovery in spite of falling output from maturing gas fields in the 1990s, and in its peak year of 2004, Canada exported over 8 million tonnes of sulphur. However, gas production in Alberta peaked in 2001, and during the 21st century Canada's sour gas production began to decline as fields mature and new fields are not tapped. The reason for this has been the rapid expansion of shale gas production south of the border in the USA, where gas prices that used to be over $10.00/MMBtu have now dropped to below $3.00/MMBtu, undercutting Canadian sour gas production.

Written down costs at existing plants mean that there is still considerable sour gas production in western Canada, but volumes continue to fall. Sour gas currently makes up about one-third of the gas produced in Alberta, which accounts for nearly 85% of Canada's sour gas production, the remainder coming from British Columbia. Figures from the Alberta Energy Regulator (AER) show that during 2017, the largest sulphur producing sites were: Shell, at Caroline, Waterton and Jumping Pound (364,000 tonnes, 301,000 tonnes and 145,000 tonnes respectively), Husky at Strachan (128,000 tonnes), AEC at Saddle Hills (130,000 tonnes), Samcams at Kaybob South (115,000 tonnes) and Kayera at Strachan (96,000 tonnes) – these seven installations between them accounted for 1.3 million tonnes of sulphur or around three quarters of Alberta's sour gas production (see Figure 1).

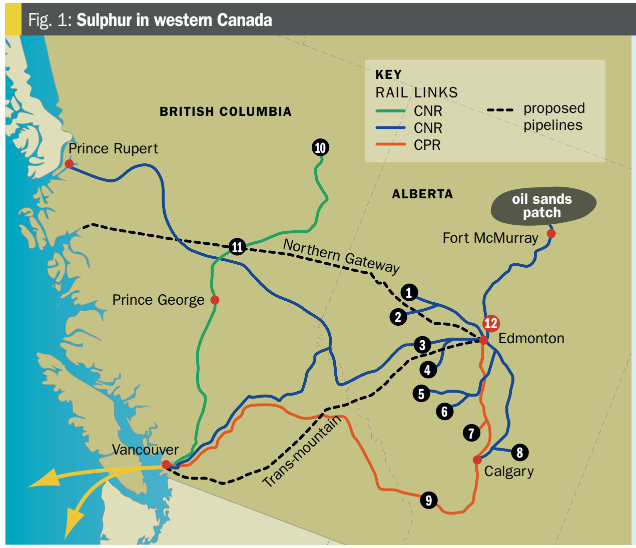
Figure 2 shows the decline in Alberta sour gas production over the past decade and a half, from nearly 6 million t/a at the turn of the millennium to less than 2 million t/a today. While there has been some balancing rise in sulphur output from oil sands processing, it has not been enough to offset the decline in sour gas production, and as a result overall Canadian sulphur production has fallen from about 9 million t/a in 2000 to less than 5 million t/a in 2017.

Conventional refining

Canada is the world's sixth largest oil producer, at 4.8 million barrels per day in 2017, representing 5.2 % 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, with a total capacity of 1.9 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,

Fig. 1: **Sulphur in western Canada**



Sulphur forming facilities

Alberta

1. Kaybob 1,2 (Fox Creek)
2. Kaybob 3 (Whitecourt)
3. Edson
4. Hanlon Robb
5. Strachan
6. Ram River
7. Shantz (Innisfail)
8. Balzac (East Calgary)
9. Waterton (Pincher Creek)

British Columbia

10. Fort Nelson
11. Hasler Flats (Pine River)

New

12. Heartland Sulphur

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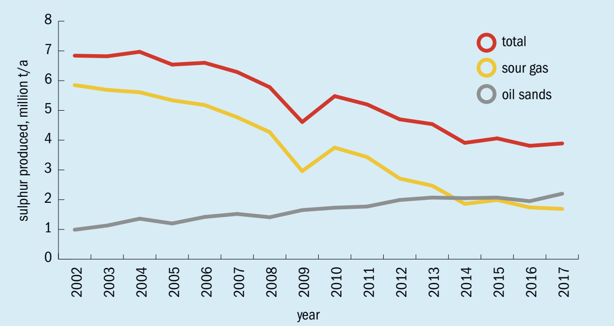
Fig. 2: **Alberta sulphur production, million t/a**



Source: Alberta Energy Regulator

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. Canadian refinery capacity had languished for some years, with the shutdowns of some smaller, less profitable units. However, late in 2017 the 80,000 bbl/d Sturgeon Refinery began operations northeast of Edmonton, the first new Canadian refinery to be built in 30 years. Like Alberta's other refineries, Sturgeon mostly processes diluted bitumen from oil sands processing.

Outside of the oil sands patch, 'conventional' oil refining in Canada produces about 600,000 t/a of sulphur, most of it in Ontario and Quebec.

Oil sands processing

Few refineries can process bitumen, so in order to reach a wider market the recovered bitumen must be upgraded to produce usable lighter fractions. Steam (in the case of in situ extraction) or hot water (for mined oil sands) are used to separate the bitumen from the sand. The bitumen is then heated and sent to drums where excess carbon (in the form of petroleum coke) is removed, and the superheated hydrocarbon vapours from the coke drums are sent to fractionators where the vapour condenses into naphtha, kerosene and gas oil. The end product is synthetic crude oil ('syncrude'), which can be shipped to refineries across North America. Currently around 40% of mined oil sands bitumen is upgraded, and Alberta has 1.2 million bbl/d of upgrading capacity. However, the bitumen can also be diluted with lighter fractions such as naphtha to produce a 'dilbit' (dilute bitumen) or even 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.

Canadian oil production in 2017 was put by the National Energy Board as 39% bitumen, 28% 'synthetic crude' made by processing oil sands bitumen, 22% light and medium crudes, and 11% heavy crudes. However, inputs to Canadian refineries was only 6% bitumen and 29% synthetic crudes, with light and medium oil making up 54% and heavy crude 11%. This is because Canada exports most of its bitumen and a significant proportion of its synthetic crude.

Oil sands typically contain about 4-5% sulphur by weight, and therefore upgrading or refining it recovers significant tonnages of sulphur. As Figure 2 shows, Alberta oil sands upgrading capacity has been slowly rising, generating 1 million t/a of sulphur in 2002 and around 2 million t/a at present. 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. This in turn has led to a number of pipeline proposals to take syncrude and dilbit either south to the US, east to the refineries of eastern Canada, or west to the Pacific for onward export to China. The most infamous of these is TransCanada's Keystone XL link, which would take bitumen from northern Alberta, across North America, to be processed on the US Gulf Coast. Environmental opposition in the US meant that the section just south of the Canadian border ran into considerable legal difficulties and became a major headache for the Obama administration, and for a while it seemed that Keystone XL was dead. However, president Trump re-authorised Keystone XL in March 2017 and the pipeline was supposedly back on. But just as this issue was coming to print, a federal judge blocked the pipeline again, and the wrangling it seems still has some way to run.

In the absence of Keystone, cross-border rail traffic carrying syncrude has increased, and other pipeline projects have come to fore. Another contentious one has been the Northern Gateway link to Kitimat on the west coast (see Figure 1), which had the backing of aboriginal communities who would have benefited from the compensation payments to be paid for crossing their land, but which was blocked by the Canadian government in 2017 on environmental grounds. Kinder Morgan has instead proposed a more southerly route from Edmonton to the coast at Burnaby near Vancouver, the Trans-Mountain Pipeline, following an existing pipeline and building a new line to triple its capacity to 890,000 bbl/d. However, with resistance from the British Columbian government, Trans Canada looked close to walking away from the project in early 2018, and so in March 2018 the Canadian government paid C$4.5 billion to buy the Trans-Mountain project from Kinder Morgan, indicating that they will develop it as a Crown corporation. With a federal court rescinding the pipeline's permit in August 2018, this project too looks to be likely to spend a long time in legal limbo.

New oil sands projects

In the meantime, the prospects for oil sands development were thought to have been dealt a deadly blow by the fall in the price of oil. Falling share prices and valuations for oil sands projects prompted a number of major companies to scale back their involvement in oil sands development or exit the field completely, including Total, Shell, Marathon, Statoil and ConocoPhillips. Nevertheless, established companies like Syncrude, Suncor, Imperial Oil, Canadian Natural

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Resources Ltd, Husky and Devon Energy have all elected to stay the course, and new money has flowed in from Asia, especially China, including Sinopec and CNOOC, and Thailand's PTT Exploration & Production.

One cause for optimism has been the reduction in production costs achieved by producers, especially from the new wave of 'in situ' production which has represented 80% of new production since 2007. While mined projects have a capex per producing barrel of up to $90,000 and a breakeven price of around $90-95/bbl, in situ projects have achieved costs per installed barrel of as low as $32,000 and breakeven costs of $68-80/bbl. With oil prices below $60/bbl for the past few years, this still made oil sands look like a poor bet, but OPEC's move to cut supply in late 2017 has seen prices around $70/bbl for most of 2018, and some oil sands projects have the expectation of prices rising further.

Labour costs have also been an issue, with wage growth in Alberta's oil industry hitting record levels. Suncor has even begun experimenting with driverless trucks to try and bring down costs, phasing them in over the next six years, with the potential loss of 400 jobs. While the number of new oil sands projects has dried up, there are still expansions being developed. Last year saw the Phase 3 expansion of Canadian Natural Resources Limited's Horizon oil sands facility, and this year Suncor has been expanding its Fort Hills operation, in conjunction with joint venture partners Teck Resources and Total, raising production from 150,000 bbl/d to 195,000 bbl/d by the end of the year, and the company says it will make an investment decision on further expansion in late 2019 or early 2020.

Overall, the Canadian National Energy Board is currently still forecasting that oil sands production will rise from just under 3 million bbl/d this year to 4.2 million bbl/d in 2030, although this would probably be dependent on additional pipeline export capacity. The question then becomes whether the sulphur encapsulated in that bitumen is recovered in Canada, in the US, or possibly even in China.

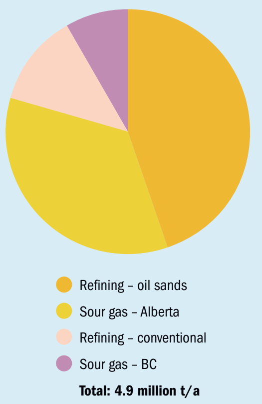
Sulphur production and export

Overall, Canadian sulphur production was about 4.9 million t/a in 2017, with about 1.7 million t/a coming from sour gas processing in Alberta and 0.2 million t/a from sour gas processing in British Columbia. Another 2.1 million t/a came from oil sands upgrading, and 0.6 million t/a from refining (Figure 3). Overall about three quarters of Canadian sulphur production now comes from Alberta. Output from oil sands was slightly up on 2016, as the Fort MacMurray region recovered from the devastating wildfires that had forced some production to shut down in 2016. This year has seen outages at Syncrude, but this has been balanced by new production from the Horizon project.

Canadian sulphur consumption, meanwhile, runs at about 0.8 million t/a, leading to a surplus of just over 4.1 million t/a, most of which is exported. In 2017, around 1.4 million t/a was exported south to the US, mainly as molten sulphur, while 2.7 million t/a was exported via Vancouver port, mainly as solid formed sulphur. Exports to the US for 2018 have actually been higher, running at 1.23 million tonnes to the end of August, about 350,000 tonnes up on the comparable figure for 2017.

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.

Fig. 3: **Canadian sulphur production, 2017**



Source: CNRL, AER

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. Heartland is a joint venture between sulphur transporter and marketer Petrosul International Ltd, and Inter-Chem Canada, part of the Oklahoma-based fertilizer marketing and distribution company the International Chemical Company. 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 11.2 million tonnes at the end of 2017, 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.

Looking forward

Alberta reckons that sulphur production in the Province will increase to 4.4 million t/a in 2018, almost all of this from new oil sands production. However, after 2018, sulphur production is expected to remain flat for the remainder of the next decade as increasing upgraded bitumen production offsets declining natural gas production. After a decade and a half of falling production as sour gas fields are run down, and a slower than expected rise in oil sands production that had been hoped to have balanced this, it appears that Canada is now settling into a 'new normal', with exports of around 4 million tonnes for the foreseeable future. ■

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Sulphur surplus continues – for now

Loading sulphur at Vancouver.

Oversupply in the sulphur market is likely to continue for the next few years, but in the longer term, large new phosphate capacity additions may run ahead of new sulphur capacity.

World production of elemental sulphur reached 64 million tonnes in 2017. Virtually all of this comes from recovered sulphur from refineries and sour gas plants, with mined sulphur only 1% of production from the couple of remaining facilities. Additions to sulphur capacity are coming from increased demand both for refined products and natural gas, as well as tighter sulphur regulations on fuels that are leading refiners to invest in additional sulphur recovery capacity.

Refinery output

Refinery output of sulphur is continuing to grow steadily for a variety of reasons. Firstly, there is the growing volume of crude that is being processed. According to BP's Statistical Review of World Energy, refinery throughputs increased 2% in 2017 to 84.9 million barrels/day (bbl/d). Refinery capacity increased by 0.6% to 98.1 million bbl/d, with the bulk of new capacity additions coming in Iran, India, China and South Korea. The International Energy Agency forecasts that oil demand will rise by 6.9 million barrels/day to 104.9 million bbl/d from 2018-2023, with half of that demand growth coming from China and India. Although global oil demand growth is slowing, as the Chinese economy turns from manufacturing towards consumer-led demand, and stringent new air quality legislation there clamps down on new demand from vehicles, this still means a million barrels per day of new demand being added every year. On the refining side, overcapacity is looming, with 7.7 million bbl/d of new capacity being built from 2018-2023, and only around 5 million bbl/d of extra refined products demand likely to be added over that period, according to the IEA. The developed world also continues to make savings in consumption of liquid fuels via a move to more efficient vehicles and the use of alternative fuels, hybrid and electric vehicles.

At the same time, new liquids production is coming particularly from the US, from fracked 'tight oil' and natural gas liquids, which are generally lower in sulphur content. This has actually left US refiners who had invested in processing cheaper, heavy, sour crudes with a shortage of this material. But they may find this a prudent investment come 2020, when the new International Maritime Organisation rules on sulphur content of bunker fuels come into force, taking the limit down from 3% to 0.5%. The expectation is that refiners who have not invested in upgrading capability will need to buy sweeter feeds in order to produce sufficient low sulphur fuel, putting an even greater price premium on sweet crudes and possibly leading more refineries to look at processing sourer crudes. The alternative to lower sulphur bunker fuels is the use of scrubbing technology or alternative fuels, but uptake of both has so far been very limited. While not all of the sulphur will be removed from heavy fuel oils, it represents a potential reservoir of 5 million tonnes per year of sulphur which could potentially be removed, until scrubbing technology achieves wider acceptance. There is still a reservoir of spare coking capacity in places like the US, and the best bet is that up to half of this sulphur may eventually find its way onto the market.

All of this is coupled with progressive moves to lower sulphur content of vehicle fuels around the world, now down to 50ppm in China and India, and some regions of China have moved further to 10ppm. Overall, in spite of the move to sweeter tight oil and natural gas liquids in the US and the fall in oil consumption in the developed world, the rise in use of sourer crudes, tighter sulphur standards and increasing demand for refined products means that global refinery sulphur output is set to increase by around 4.5 million t/a over the next five years, mainly in South and East Asia and the Middle East, where the largest wave of new refining capacity is being built.

Natural gas

Use of natural gas is also rising steadily around the globe, mainly for power production. Global gas consumption has risen from 2.96 trillion cubic metres in 2007 to 3.67 trillion cubic metres in 2017, according to BP figures. This growth has been strongest in Asia, which accounted for about half of that increase, but there has also been considerable growth in the Middle East, where rapidly rising populations and demand for electricity in fast-growing cities like Dubai and Abu Dhabi have also pushed growth, and there has also been significant demand growth in North America, as gas begins to replace coal as a power generation fuel. Part of this has been due to the perception of gas as a lower carbon source of electricity than coal or heavy oil, but in North America the shale gas boom has also lowered prices and made gas much more competitive with coal as a feedstock for power and chemical production. Gas consumption worldwide increased by 3% in 2017, and the IEA projects that it will continue to rise by an average of 1.6% year on year from 2018-2023.

Unconventional gas

Production of gas from so-called 'unconventional' sources continues to grow. In North America this is of course shale gas, the story of which is now a well-worn one, but growth in production from coal-bed methane, especially in countries like Australia, China and India, has also been a major phenomenon. The shale gas boom has had a significant impact on sulphur availability in North America, as it has undercut the production of sour gas in the US and Canada, while the shale gas itself is mainly fairly sweet. The effect has been to remove up to 4 million t/a of sulphur production from North American sour gas over the past decade. The spread of shale gas development has been much patchier outside North America, however, with environmental opposition in Europe and technical difficulties in Poland. China has been keen on shale gas as a way of supplementing its relatively meagre gas output, but has taken a while to adapt to the technical challenges involved, with difficult geology and shortages of water. Nevertheless, many now believe China could be on the verge of a boom in shale gas production that could take its gas output from 9 bcm to 17 bcm in just the next couple of years. This is still fairly small beer compared to US output, but could be something to watch over the medium term future.

Sour gas

In the meantime, where sweet, conventional or unconventional gas is not available, producers in some regions have turned to sour gas production, which has been responsible for generating considerable new volumes of sulphur worldwide. While, as noted, sour gas production is continuing to fall in North America, three main regions are still increasing their sour gas production; China, Central Asia, and the Middle East.

Chinese production comes from three gas plants, at Chuangdongbei, Puguang and Yuanba. Production at Puguang, the largest plant, has been down over the past couple of years on its initial estimates, but this has been balanced by increased production from Yuanba and the start-up of Chuangdongbei Phase 1. Phase 2 is now set for start-up by 20201, by which time sulphur production from Chinese sour gas is likely to reach 3 million.

In the Middle East, Abu Dhabi's huge Shah sour gas project began producing in 2015, and has an output of 3 million t/a of sulphur at capacity. Adnoc is now looking to increase production at Shah by 50% over the coming years, and has other sour gas projects under development. Saudi Arabia has new sour gas projects which are being processed at the Wasit gas plant, and a new facility is under construction at Fadhili which is due for completion next year. Qatar's Barzan LNG expansion has been put back a couple of years, and now may not start up before 2022, but is expected to add another 1.5 million t/a of sulphur capacity. There are also additional incremental volumes coming from the final phases of Iran's South Pars project and Yibal Khuff in Oman.

Central Asia has seen the start-up of the South Yolotan/Galkynysh sour gas plant in Turkmenistan, although output is limited by pipeline export capacity, and full capacity may only come with the completion of the Trans-Caspian gas pipeline in a few years time. In Kazakhstan, the North Caspian Operating Company seems to have finally sorted its problems with sour gas corrosion of undersea pipelines and began forming and exporting sulphur late last year. Kashagan sulphur output is expected to reach 1.1 million t/a at capacity. There is also the Kadym project in Uzbekistan, although indications are that the sulphur produced will be stockpiled rather than exported.

For several years there were fears that the rush of new sour gas projects would unleash a flood of sulphur onto international markets. However, technical difficulties and project delays have muted this to a considerable extent, and the actual addition of new sulphur to market has not been as fast as feared, allowing demand to keep pace. Even so, all of these projects taken together represent about 6.0-6.5 million t/a of new sulphur potentially coming to market over the next five years.

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Sulphur consumption

Most sulphur – around 90% – is consumed as sulphuric acid. Sulphuric acid is the most widely used industrial chemical, with a market size of more than 265 million t/a in 2017. Burning elemental sulphur is however not the only source of sulphuric acid – around 8% comes from roasting of iron pyrites, mainly in China, and another 30% from capture of sulphur dioxide emissions at metallurgical smelters. The smelter acid segment is involuntary production and tends to be relatively independent of sulphur prices, but instead determined by the markets for base metals, especially copper. There is however some interchangeability between sulphuric acid and sulphur for some producers, like OCP in Morocco, who can to a limited extent turn from buying sulphur on the international market to importing sulphuric acid directly instead. This complicates the market for elemental sulphur slightly, as it must to an extent compete with pyrites and smelter acid. As smelter acid, as a waste product, can often be relatively inexpensive, it can often be preferred where there is a source of supply locally. But the difficulties of storing and transporting large volumes of acid have conversely also meant that some consumers have installed sulphur burning capacity in order to gain greater control over feedstocks. This has happened in Cuba and Chile in recent years. Supply disruptions in the smelter acid sector over the past two years and the shutdown of the Tuticorin smelter in India have also helped to push sulphuric acid prices back up, helping to increase demand for sulphur burned acid, although potentially also causing demand destruction in, for example, the single superphosphate industry.

Likewise, while China's pyrite acid capacity has remained remarkably durable, gaining electricity credits from acid production and selling iron fines to the steel industry, increasing Chinese regulation on emissions of sulphur dioxide may force the closure of a significant portion of this production, leading to increased requirement for acid from sulphur burning acid plants, and hence additional sulphur, perhaps over 1 million t/a.

Overall, however, aside from these factor, demand for elemental sulphur for acid production is dominated by agricultural uses, via the production of single superphosphate (SSP), ammonium sulphate and especially phosphoric acid for phosphate fertilizer production – mainly mono- and di-ammonium phosphate (MAP/DAP). This accounts for around 60% of all sulphuric acid consumption. Acid used in the leaching of rocks for metal extraction – primarily copper, but also nickel, uranium, rare earths and gold, takes another 10%. The rest is consumed by a wide range of industrial uses, including titanium dioxide pigment production, especially in China and Europe, caprolactam manufacture, and many others.


PHOTO: MARK EVANS

Liquid sulphur shipping at the port of Tampa.

Phosphates

The past decade has been the story of massive capacity addition in the phosphate industry, most of it in China, which went from a major importer of diammonium phosphate to a major exporter, with considerable overcapacity domestically. From about 2014 this pushed the phosphate market into oversupply, but the response to low prices was a considerable uptick in demand, and by 2017 the phosphate market had virtually moved back into balance – the closure of less competitive Chinese capacity, shutdowns due to tightening environmental regulations, and production discipline from the major Chinese producers also helped close this gap between supply and demand.

Table 1: **Major sulphur exporters and importers, 2017, million t/a**

Exporters		**Importers**	
Abu Dhabi	4.5	China	11.0
Canada	4.1	Morocco	5.4
Saudi Arabia	2.8	Brazil	2.2
Russia	2.7	United States	2.0
United States	2.3	India	1.2
Kazakhstan	2.2	Australia	0.8

Over the next few years, fresh demand for phosphate fertilizer is expected in India, Latin America (especially Brazil), Africa and Southeast Asia, balanced slightly by a reduction in China, increasing demand by about 5.5 million t/a P_2O_5 by 2023. New capacity meanwhile is coming mainly from Morocco and Saudi Arabia. In Morocco OCP continues to massively expand its production of downstream mono- and di-ammonium phosphate, capturing more value by turning from a rock exporter to a low cost processed phosphate exporter. In Saudi Arabia, Ma'aden is part of a general move to try and move the Saudi economy away from its dependence on oil. Sulphur from the new sour gas plants is being used to process phosphates at the growing Ras al Khair phosphate hub on the Kingdom's east coast, receiving rock from the mines in the northwest of the country. The second major Ma'aden expansion came on stream this year, and a third is now in the pipeline. Egypt is also increasing production, and there are projects in Russia, Turkey and Indonesia. The total new capacity over the period to 2022 amounts to considerably more than the increase in demand. However, there are likely to be more closures in the US and Canada, and the extent to which Chinese capacity will be rationalised remains a major wild card.

Each tonne of processed P_2O_5 requires on average about three tonnes of sulphuric acid, which in turn requires about one tonne of sulphur to be burned. Thus if all of the new phosphate capacity were produced by sulphur burning, then new phosphate demand would require about 5.5 million t/a of additional sulphur.

Metal leaching

Metal leaching operations were a growing source of demand for sulphuric acid and sulphur as more and more copper and nickel was required to fuel China's industrial boom. Processing of uranium ores, especially in Kazakhstan, where relatively acid-hungry processes and alkaline rocks made for extra acid demand, also contributed to the 20 million or so t/a of sulphuric acid now consumed by acid leaching. Chile had been an enthusiastic proponent of copper leaching, and there were also major copper leaching operations in Peru and the US. However, the slowdown in the Chinese economy led to a collapse in copper and nickel markets, and the leaching operations tended to be towards the higher end of the cost curve and were often easiest to idle when there was overcapacity. Nickel leaching also faced technical difficulties – nickel laterite ores require much more aggressive conditions than copper sulphides, and the high pressure acid leach (HPAL) process proved expensive and technically challenging. The spread of pyrometallurgical processes for recovering so-called 'nickel pig iron' in China and Indonesia effectively put a stop to new HPAL nickel production.

The past couple of years however have seen a rebound in copper and nickel markets as China returns to growth and overcapacity has eroded due to shutdowns. There is renewed interest in copper leaching, now focusing on Africa's copper belt, as well as Chile, while on the nickel side the first new HPAL projects for several years have been announced recently, and metallurgical demand for acid seems set to recover over the next few years.

Supply/demand balance

So where does this leave the overall supply/demand balance for sulphur over the next five years? New supply from refining and sour gas, taken together, adds about 10.5 million t/a of capacity, provided that there are no further project delays, while new demand may only reach 8 million t/a over the same period. The market is and continues to be in surplus, although the new supply is concentrated towards the start of the period, while demand is more spread out, meaning that the market may actually push back into balance or even deficit by 2021.

On a regional basis, as Table 1 shows, Abu Dhabi has taken over as the largest sulphur exporter from Canada after the start-up of the Shah sour gas project. Exports from Canada have been falling, as our article elsewhere this issue discusses, due to reduced output from sour gas production, but may have reached a stable point now. Saudi Arabia has more demand coming from phosphate processing but also more supply coming from sour gas production, while Russia's domestic demand for sulphur is also increasing due to new phosphate and industrial production. The US remains a slight net exporter, mainly from refineries on the US Gulf Coast. Exports from Kazakhstan are likely to increase now that the Kashagan oil and sour gas field is running close to capacity.

On the import side, China remains by far the largest importer, but rising production from sour gas and new refineries and closures in the phosphate industry should reduce this, balanced slightly by the switch away from pyrite-based acid production. Morocco's demand continues to increase due to its huge phosphate expansions, and Brazilian and Indian demand should increase slightly for the same reason. Australia has seen the closure of the nickel leaching plant at Ravensthorpe, which has reduced sulphur demand. ■

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Connecting the global sour gas community

MESPON 2018, the 5th Annual Forum, took place October 14-17 at the Sofitel Abu Dhabi Corniche, Abu Dhabi. Organised by UniverSUL Consulting and supported by ADNOC, this year the programme was expanded to include a new innovation/technology day.

The Annual Middle East Sour Plant Operations Network Forum (MESPON) has become one of the industry's premier events for knowledge exchange and networking, originally focused primarily on sulphur recovery, but now representing all groups along the sour gas value chain. MESPON's vision is to address everything from sour gas drilling, to production, to sweetening, to sulphur recovery and sulphur handling.

Each year the programme and the number of attendees has been growing. Another new feature of this year's programme was the innovation/technology day, combining presentations and exhibitions, on the first day of the conference, dedicated to R&D and other advancements that have the potential to transform the sour gas industry.

ADNOC Sour Gas displayed some of the innovative technologies used in its Shah gas plant, which has the highest H_2S content in the region. They include: the longest corrosion resistant alloy (CRA) pipelines, the largest SRUs in the world and the first granulated sulphur rail transport system in the Middle East. In addition, ADNOC Sour Gas presented their new skid-mounted dirty sulphur remelter, designed to reduce waste, reduce cost for disposal of dirty sulphur and increase production. The unit has been designed for a minimum output of 5 t/d sulphur with 99% purity in a low maintenance, batch operation.

ADNOC Gas Processing showcased a variety of innovative technologies, two of which are already under demonstration: a black powder detection device and an Automated Guided Vehicle (AGV) that can perform pipeline inspections.

Ametek displayed its latest tail gas analyser for air demand feedback control. Now in its 4th generation, Model 888 NSL enhances reliability with improved features such as flow control to adapt to different load conditions automatically, thermal management and ambient temperature specification to 60°C without the need for utility cooling, improved safety considerations with double-block isolation from the process, as well as reliability at a safe distance with web-enabled smart diagnostics.

Elemental sulphur deposition (ESD) and sulphur plugging can be a problem for gas transportation and purification, sulphur handling and refining operations. **Arkema** showcased a powerful new sulphur solvent – SULFATEK™ – to dissolve and remove deposited sulphur, restoring operations to optimal conditions with minimum process disruption. It provides 100% sulphur dissolution via a catalysed reaction which exhibits fast kinetics.

Alberta Sulphur Research Ltd (ASRL) conducts research in the field of chemistry as it relates to the science and technology of sulphur and its compounds with particular emphasis on the production, processing and utilisation of sour natural gas, sour crude oils, oil sands and their related products. ASRL's 2018-2019 core research programme, determined by its members, consists of 19 projects covering a wide range of topics. At MESPON 2018, Dr Rob Marriott focussed on ASRL's latest work on sulphur related corrosion within sulphur production and recovery systems.

Industrial Ceramics recently engaged ASRL to conduct a series of experiments to better understand the interaction of wet sulphur corroded carbon steel within the Claus environment. During the conference, Industrial Ceramics performed wet sulphur corrosion experiments to demonstrate the interaction of the product of wet sulphur contact corrosion with ceramic fibre paper (an important part of the tubesheet protection system in waste heat boilers). This "new" corrosion mechanism can impact ferrule integrity during shutdown and/or start up procedures, especially during emergency shutdowns.

Jacobs Comprimo® together with **COOL Separations B.V.** have developed a solution for treating water effluent streams in SRU/TGTUs containing high salt/sulphate concentrations. An innovative, low energy, chemical free, technology for treatment of high salinity waters, Eutectic Freeze Crystallisation, developed by COOL Separations can treat this type of stream in a far more energy efficient way.

Khalifa University is involved in a research project with the aim to advance the so-called Solar Sulphur Cycle (SSC) to address challenges with respect to economical energy storage technologies for concentrated solar power (CSP) plants. During the day, solar thermal energy from concentrating mirrors is thermodynamically stored by decomposing sulphuric acid into sulphur, water and oxygen. At night, elemental sulphur is burned and the waste heat recovered as HP steam for power generation.

CECAS (Centre for Catalysis and Separations), part of Khalifa University, showcased the current topics it is working on. The Center's uniqueness arises from its extensive network with world renowned catalysis institutions and industries. The center implements a multilateral approach whereby multi-scale simulation methods are coupled with experiments and characterisation techniques to elucidate the fundamentals of problems and provide practical solutions.

NEO Monitors showcased its LaserGas™ iQ2 analyser, the first tunable diode laser absorption spectroscopy (TDLAS) analyser to measure up to four gases (O_2, CO, CH_4, H_2O) and temperature in one unit, eliminating the need for multiple units for combustion analysis.

nVent and **Topside Solutions** showed how artificial intelligence (AI) can be applied for proactive and predictive analysis of sulphur transport pipelines, giving operators the interactive ability to address a potential problem scenario before it becomes a crisis. Utilising sulphur pipeline operating data, streamed from a pipeline's fibre optic distributed temperature sensing (DTS) system, decision-based outcomes become much more predictable.

Prosernat and **University of Strasbourg – SATT Conectus** introduced an innovative catalyst, NMC@SiC, which shows very high stability for direct oxidation of H_2S into sulphur in the presence of large amounts of BTX (up to 5,000 ppm mol toluene). NMC@SiC is a nitrogen-doped carbon metal-free catalyst on a silicon carbide (SiC) thermal conductive support. The NMC@SiC catalyst has been demonstrated at the lab scale and opportunities are being sought for demonstration in real conditions. Based on lab performances, the NMC@SiC catalyst coupled to the Smartsulf™-DO process would be an effective low capex and opex solution to treat H_2S lean acid gas polluted with BTX.

Schlumberger highlighted the limitations of traditional coiled tubing (CT) pipe integrity management practices, gave an overview of real-time magnetic flux leakage (MFL) CT pipe integrity monitoring and provided a case study from its implementation in the Shah field (a high pressure, high temperature (HPHT) ultra-sour environment) to provide safer and more efficient coiled tubing interventions.

Shell Global Solutions International B.V. displayed its Shell Turbo Trays® – column internals that can be applied in acid gas removal units, where gas contaminants such as H_2S and CO_2 are scrubbed from the gas using a variety of solvent technologies. They feature integrated contact and separation zones that significantly increase the interfacial area and contact between the gas and liquid and hence allow for high mass transfer rates.

Sulphur Experts showcased its advanced onsite analytical method to determine sulphur compounds in LPG. Measured sulphur compounds include H_2S, COS, R1-R4 mercaptans, DMS and DMDS. With this method, onsite analysis of pressurised LPG streams is possible in under 20 minutes with a minimum detection limit of 1-2 ppm.

Transcend Solutions exhibited an aerosol separator. The demonstration unit produces an oil aerosol similar to that which may be present in pipelines resulting from compressor lube oils and condensation of hydrocarbons. The capabilities of conventional and advanced separator technologies were demonstrated.

Innovation through collaboration

The keynote address on Day 1 examined the power of collaborative innovation and was presented by Dr Sigvald Harryson of **iKnow-Who**. Using several high profile global companies as examples, Sigvald demonstrated the benefits of collaboration when innovating and introduced the idea of disruptive innovation, a new proven methodology to innovate through collaborative competitions in which teams of academic or professional experts collaborate and compete to solve an innovation challenge.

Li-Sulphur batteries were proposed as the dream collaborative innovation which could lead to a breakthrough for the UAE for several reasons:

- The energy density of Li-S batteries is ten times higher than lithium batteries, i.e. 2500 Wh/kg versus 250 Wh/kg. The higher capacity is a result of using a metallic lithium anode (instead of intercalated lithium ions in graphite), as well as using elemental sulphur in the cathode.
- Li-S batteries use no cobalt (many Li-ion batteries use cobalt as a cathode material) and are thus not vulnerable to cobalt shortage and price increases (60% of the world's cobalt comes from DR Congo and 90% of all processed cobalt is owned and sold by Chinese companies).
- Sulphur is plentiful and non toxic.

SULPHUR
ISSUE 379
NOVEMBER-DECEMBER 2019

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Sulphur tank heating solution combats corrosion problems

B. Forbes and **D.J. Cipriano** of Controls Southeast Inc. (CSI) discuss a case study illustrating corrosion rates of an externally-heated sulphur storage tank. The design approach for heating the sulphur storage tank and the inspection results confirming its operation are reviewed. An internal inspection after nine years of operation indicated that the remaining life of the tank shell and roof is expected to exceed 70 years.

Challenges of sulphur storage tanks

There are several unique challenges associated with storing sulphur in field-erected tanks. The most significant challenges are those related to safety and those related to maintenance. Over the last decade, sulphur tank safety concerns have become more widely considered with more publications describing the concerns. The primary safety concerns are as follows:

Accumulation of H_2S in the tank vapour space

Sulphur produced via the modified Claus process will contain high levels (up to 500 ppmw) of dissolved and chemically integrate H_2S. Unless the sulphur goes through an additional degassing process, it will slowly release the H_2S into the vapour space as a gas. The lower explosion limit (LEL) of H_2S gas mixed with air is roughly 4 vol-% (though it changes with temperature and other factors). Additionally, H_2S in air is lethal at concentrations as low at 500 ppm. It is therefore critical that the accumulation of H_2S gas in the tank vapour space be addressed.

Providing the tank with an inert vapour space (e.g. nitrogen blanket) is one method of addressing the LEL concern. However, this method still allows a significant build-up of H_2S gas to accumulate. This build-up could present an explosion hazard if oxygen (air) were to be inadvertently introduced; it could also present a health hazard if the vapour were to be inadvertently released. For these reasons, and others described later, a continuous sweep of ambient air is the more preferred method of handling the tank vapour space.

The required rate of sweep air is calculated based on the sulphur turnover rate in the tank, the maximum resulting H_2S release rate, and the vapour turnover rate required to stay below the 4 vol-% LEL. Excessively high sweep rates should generally be avoided as they place a significant heat load on the tank which can lead to sulphur freezing and blocking nozzles / vents, as well as corrosion – both of which can result in additional safety hazards

This sweep air arrangement can be implemented in one of two forms: A 'forced sweep' uses an ejector or blower to move air through the tank and deliver it to a safe location for release or processing. A 'free convection sweep' uses strategically-located vents to induce a draft that pulls air through the tank and releases it from a vent in the roof. Free convection sweep is typically preferred where the sulphur is expected to have minimal H_2S content. Forced sweep is typically used where the sulphur is expected to have high H_2S content and the exhaust vapour must be treated for health, safety, and environmental reasons.

A final point regarding H_2S accumulation is the need to avoid ignition sources. Sulphur has a relatively low electrical conductivity and can therefore build up a static charge – especially if it is allowed to free-fall. The use of a dip-tube is recommended where sulphur is supplied from a roof nozzle. A second common ignition source is various forms of pyrophoric iron sulphides.

Accumulation of pyrophoric material

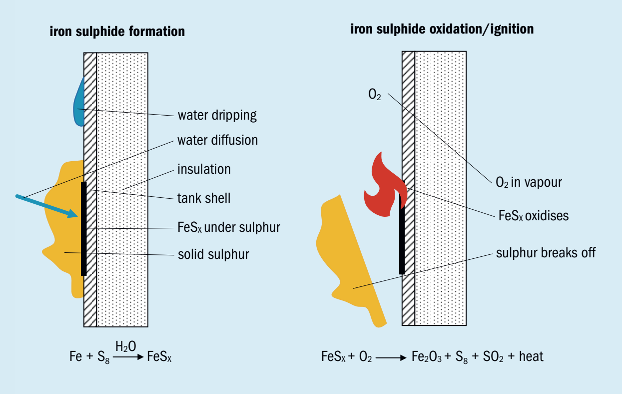
When combined, sulphur, steel, and water react together to form various iron sulphides. These sulphides are pyrophoric – when exposed to oxygen, a rapid exothermic oxidation reaction occurs. With a sufficient mass of accumulated sulphides, the temperature resulting from the oxidation reaction can be high enough to ignite H_2S in the vapour space or ignite the sulphur itself.

To avoid this scenario, either the accumulation of sulphides or the oxidation of sulphides must be prevented.

Fig. 1 illustrates the iron sulphide ignition mechanism.

One method of preventing the formation of iron sulphides is to maintain all carbon steel surfaces above 100°C to prevent the accumulation of liquid water. The presence of sulphur can frustrate efforts to this end as solid sulphur that builds up on the interior surface insulates the wall and drives down the temperature. Water vapour can penetrate the porous sulphur, condense at the wall, and form iron sulphide. Worse yet, iron sulphide formed in this manner can accumulate in large masses that are only exposed to oxygen when chunks of sulphur fall away from the wall.

Fig. 1: **Iron sulphide ignition mechanism**



Source: CSI

These large masses of sulphides reach very high temperatures when they suddenly oxidise together.

A better approach is to maintain all carbon steel surfaces above 120°C to prevent sulphur from freezing. This prevents the formation of iron sulphides. Even if some small cold spots exist, without large sections of solid sulphur accumulation, it is unlikely that large masses of iron sulphide will form. Small masses of iron sulphide not buried under frozen sulphur are typically not a problem; they tend to oxidise as they form and never reach the critical mass needed to achieve dangerously high temperatures.

One might attempt to stop the iron sulphide formation by removing water from the system.

Unfortunately, this approach is not likely to succeed as there are numerous potential water sources, including:

- leaking internal steam coils;
- inadequate vent caps;
- damaged tank roof or nozzles;
- humidity in ambient air;
- oxidation of H_2S where:

$$H_2S + O_2 \rightleftharpoons H_2O + SO_2$$

rust-catalysed break-down of H_2S where:

$$H_2S + O_2 \rightleftharpoons S_8 + H_2O + SO_2$$

(note this is highly simplified as there are several reaction steps with several intermediate FeO_x and FeS_x molecules);

- use of snuffing steam.

Use of an inert vapour space (nitrogen blanket) will prevent the ignition of iron sulphides. However, this is generally considered to carry significant risk as without oxygen, any sulphides that do form will accumulate over time. When the nitrogen blanket is removed (intentionally or unintentionally) and oxygen enters the tank vapour space, there may be a very large mass of accumulated sulphides available; these will likely burn at a very high temperature, increasing the risk of a tank fire. Using an ambient air sweep will tend to oxidise the sulphides as they form via the mechanism described above and is generally considered the safer approach.

Safety summary

While each sulphur tank application should receive a specific review, the following high-level recommendations should be considered for any sulphur tank application:

- sweeping the vapour space with ambient air is generally preferred over an inert blanket;
- the sweep rate must be high enough to prevent the H_2S concentration from reaching the LEL;
- the sweep vapour must be handled in a way that does not present an HSE concern;
- the tank should be heated in such a way that the formation of iron sulphides is prevented or severely limited;
- the sweep air system (including tank nozzles) should be heated in such a way that prevents plugging.

Tank corrosion

The primary challenges to sulphur tank maintenance are corrosion and plugging. Problems with plugging are immediately evident and can be addressed with adequate heating. Problems with corrosion can progress undetected and result in extensive damage as well as potentially hazardous material release events. There are several different corrosion mechanisms that can contribute:

Internal corrosion can occur due to the iron sulphide reaction described above. This generally occurs in the vapour space and can occur rapidly.

Internal corrosion can also occur in the more conventional manner due to the presence of water. Common sources of water are as discussed.

External corrosion can occur due to ambient water exposure. This mechanism is not unique to sulphur storage. Water that penetrates the insulation may sit against the external tank surface for an extended period as evaporation from under the insulation will be slow. Field-erected storage tanks are also subject to water intrusion to the space between the tank bottom and the concrete pad (or ring-wall). Again, evaporation from this area will be slow and significant corrosion can result.

External corrosion can occur due to spilled sulphur. There are several mechanisms by which spilled sulphur can accelerate the corrosion of steel surfaces. Mixing sulphur and water can generate small amounts of sulphuric acid that eat through the steel. Together, sulphur, water and steel can react to decompose the steel and form iron sulphides as described above. Finally, thiobacilli bacteria can also produce sulphuric acid as they digest the sulphur. Sulphur tends to accumulate around the tank vents and on the ground at the base of the tank, these are the areas that tend to be most susceptible to this form of corrosion.

Fig. 2 shows an example of sulphur tank shell corrosion. Fig. 3 shows an example of sulphur tank structure corrosion.

ControTrace sulphur tank heating solution

CSI has developed a tank heating technology utilising ControTrace engineered bolt-on jacketing. The system uses a distributed heating arrangement that provides uniform heating to the entirety of the tank

SULPHUR
ISSUE 379
NOVEMBER-DECEMBER 2019

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Fig. 2: **Sulphur tank shell corrosion**

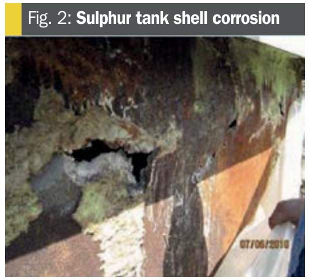


PHOTO: CSI

Fig. 3: **Sulphur tank structure corrosion**

PHOTO: CSI

Fig. 4: **ControTrace tank roof heating**

PHOTO: CSI

Fig. 5: **ControTrace tank shell heating**

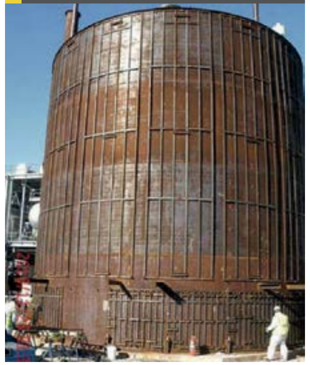


PHOTO: CSI

shell and roof surfaces. Nozzle and instrument heating can also be provided. The goal of the design is to address multiple safety and reliability concerns by addressing the various root causes:

- Prevent H_2S accumulation in the vapour space by heating of the vent nozzles. This prevents sulphur solidification in the nozzles that could restrict or block the vapour flow.
- Prevent iron sulphide formation by maintaining the shell and roof above 120°C at all locations. This prevents sulphur solidification and water condensation which prevents iron sulphide formation.
- Prevent plugging of nozzles by providing direct heating.
- Prevent corrosion by maintaining the tank wall and roof temperature. Preventing water and sulphur condensation on the tank surfaces effectively blocks the corrosion mechanisms described.

Additionally, the ControTrace external heating system provides heat directly to the liquid sulphur in the tank. This eliminates the need for internal coils, subsequently eliminating costly coil maintenance and potential water intrusion into the tank.

The ControTrace heating system is comprised of multiple heating panels, each comprised of multiple individual heating elements. The heating elements are spaced at a specified distance that maintains the tank wall temperature above the target temperature (typically 125°C) at all locations. Additionally, the panels themselves are shaped to fit closely together and to wrap closely around nozzles and other tank protrusions. In this way, all locations on the tank shell and roof are maintained above the target temperature.

Maintaining the liquid sulphur temperature typically requires additional heat input to offset the heat loss into the ground. The ControTrace heating panels located at the bottom of the tank wall typically utilise additional heating elements in order to provide the additional heat required. This is especially critical when the liquid level is low and the liquid contact area with the heated tank wall is reduced.

CSI determines the heating system design and predicts the tank temperatures utilising a proprietary finite-difference model. The model accounts for all relevant heat paths to determine both the liquid and the vapour temperature in the tank. Also, the model calculates the tank shell and roof temperature profile based on a given ControTrace element spacing. In this way, not only is the sulphur temperature maintained, but also a uniform shell and roof surface temperature. CSI's thermal model was developed using CFD modelling to verify uniform sulphur temperature distribution within the vessel. The model has been validated with detailed field temperature measurements including infrared imaging.

With each panel custom-fabricated for the application, the ControTrace heating system has several major advantages over other external heating systems:

- the element spacing and panel locations are fixed; thus the wall temperature is assured at all locations;
- each panel is an independent unit attached to a pre-determined location on the tank;
- thus removing any guesswork and minimising the labour required to install the system;
- panels are arranged in columns with a single steam circuit per column; thus minimising the number of circuits and required steam infrastructure.

Figs 4 and 5 show examples of ControTrace tank roof heating and tank shell heating respectively.

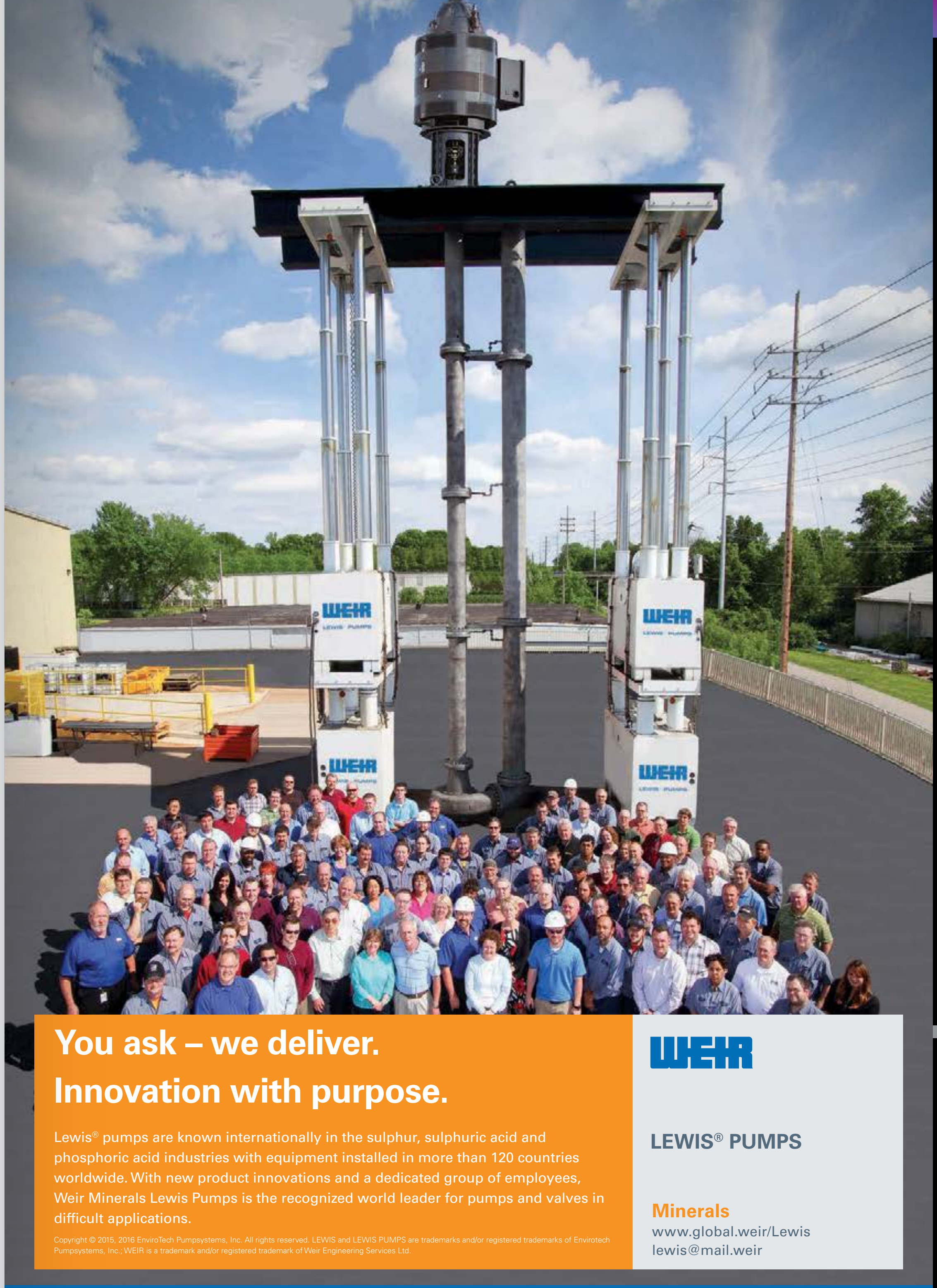
Fig. 6 shows CSI tank model macro-level heat transfer accounting and Fig. 7 shows a thermal image of a ControTrace-heated sulphur tank interior.

Historical experience of a petroleum company

Prior to 2006, sulphur tanks at a major petroleum company's gulf coast refineries were heated primarily with internal steam coils. The tanks were fully insulated, but no additional methods were employed to maintain the wall or roof temperature. These tanks did not typically last longer than ten years before full replacement was required due to extensive corrosion.

Corrosion would occur in several locations with the roof and upper shell being the most common. Corrosion of the roof and upper sidewall would occur both from the inside and from the outside. Corrosion from the inside was likely due to iron sulphide formation; corrosion from the outside was likely due to ambient water contact.

Additionally, the internal steam coil would occasionally fail and release steam



SULPHUR
ISSUE 379
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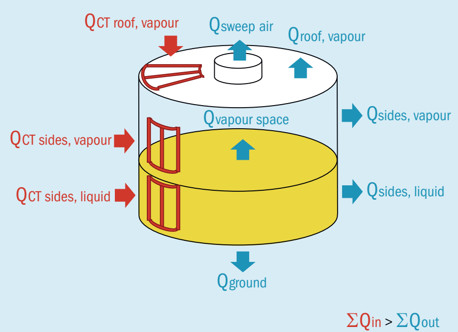
Fig. 6: **Tank model macro-level heat transfer accounting**



Source: CSI

Fig. 7: **Thermal image of ControTrace-heated sulphur tank interior**

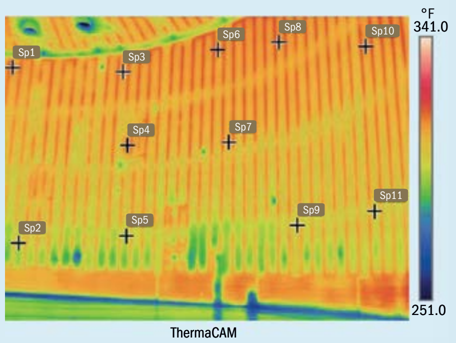


IMAGE: CSI

into the tank. The increased moisture content would accelerate the formation of iron sulphide and compound the problems.

Repairs were typically required on a yearly basis to patch or replace corroded sections. Implementing repairs required that the tank be taken out of service and cleaned so that maintenance personnel could enter the tank. This process was both costly and disruptive to plant operations.

The search for a better way

In 2006, a sulphur tank at one of the petroleum company's gulf coast refineries was identified as being beyond its usable service life; this sulphur tank was only seven years old. The petroleum company started looking for an alternative tank heating method to apply to the replacement tank. This heating system needed to increase tank safety and reduce tank corrosion to extend the service life. Preventing the formation of iron sulphides was considered to be of primary importance as this would reduce the amount of flammable material in the tank as well as reduce the corrosion rate. Maintaining the entire tank wall and roof above the freezing point of sulphur was expected to prevent corrosion. The petroleum company established two key improvements that they wanted to see in a tank heating system:

- the heating system should be configured in such a way that steam leaks would not introduce additional moisture to the interior of the tank;
- the heating system should provide heat to the shell and roof.

At the time, CSI had extensive experience heating tanks and vessels using ControTrace panels; these were typically applications where the objective was process temperature maintenance.

CSI also had extensive experience heating sulphur vapour and tail gas lines where the objective was to maintain a uniform pipe wall temperature. CSI's experience with sulphur tanks specifically, where the objective is both process and wall temperature maintenance, was limited to only two prior applications in 2003 and 2005 (and one concurrent 2006 application). These were working well but were young enough that a detailed review of the tank condition had not yet been performed. Thus, the use of ControTrace on sulphur tanks was a relatively new technology.

The petroleum company recognised that CSI's ControTrace external heating system met and exceeded their criteria. Specifically, the ControTrace heating system not only provided heat to the tank shell and roof but did so in a way that assured a uniform surface temperature throughout. The petroleum company therefore chose this technology for their new sulphur tank at the gulf coast refinery.

The new sulphur tank

In 2007 the petroleum company commissioned a new sulphur tank at the gulf coast refinery. The tank is 40 ft (12.2 m) diameter by 48 ft (14.6 m) tall and fabricated from A36 carbon steel. Sulphur in the tank typically contains roughly 100 ppm H_2S. The tank utilises CSI's ControTrace heating system designed to maintain the sulphur at or above 275°F (135°C) and the tank wall/roof surface at or above 255°F (124°C). The system is comprised of external, bolt-on heating panels applied to both the shell and the roof. ControTrace heating elements were also provided for various nozzles including the roof vents.

The ControTrace panels are attached with a combination of circumferential cables on the shell and studs on the roof. Overall, the installation went smoothly. A few improvements to the installation hardware were identified including: increasing the cable length, decreasing the stud length, providing extra attachment hardware near large nozzles where tank wall distortion is likely, and improving the instructional clarity of the documentation. CSI's current offering considers these and other design improvements.

In 2016 the petroleum company performed the first major inspection of this sulphur tank. No issues of concern were observed in the nine years of operation between 2007 and 2016. The inspection revealed corrosion of the tank floor, but no significant corrosion of the heated tank wall, roof, or nozzles. Highlights of the inspection by tank region are as follows:

Tank external

Insulation deterioration was noted at several locations. One quadrant of the roof had particularly poor insulation; regular water intrusion was likely occurring in this area. At the base of the tank, significant corrosion was observed on the under-side of the chime (joint between the shell and the tank bottom). Additionally, sulphur was observed seeping out from under the tank at two locations around the tank perimeter. Some cracking and chipping of the concrete tank foundation was observed, particularly in the area closest to the tank base.

Fig. 8: **Tank chime overview (bottom corner)**

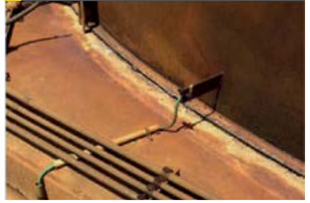


PHOTO: CSI

Fig. 9: **Corrosion and scale under tank chime**

PHOTO: CSI

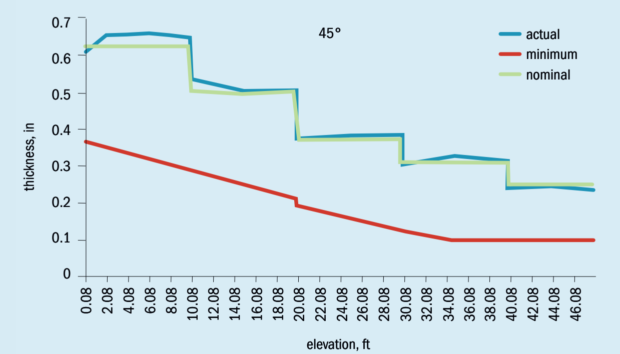
Fig. 10: **Typical interior shell/roof surface with light coating of rust**

PHOTO: CSI

Fig. 11: **Typical tank floor surface with bottom-up corrosion near perimeter**

PHOTO: CSI

Fig. 12: **Tank shell measured thickness compared to nominal and minimum**



Note: Single point of wall thinning at 0.08 ft elevation

Source: CSI

Tank roof and vent nozzles

Ultrasonic wall thickness measurements were taken at 24 different locations on the tank roof and 4 locations on each vent nozzle. A light coating of rust was noted on both the internal and external surfaces, but there was no scale/pitting and UT measurements showed that no wall thinning had occurred. The vents were all clear with no significant sulphur build-up.

Tank shell

Ultrasonic wall thickness measurements were taken at 156 different location on the tank shell. Again, a light coating of rust was observed on both the internal and external surfaces. Wall thinning of the shell was observed only on the bottom 1 inch near the chime. Wall thinning in this region was calculated to be occurring at a rate of 0.0034 inch/year. At this rate, the tank wall thickness is projected to drop below the design thickness in the year 2082.

Tank floor

Ultrasonic wall thickness measurements were taken at 209 different locations on the tank floor. Measurements at 32 of those locations showed that the floor thickness was at or below the design thickness. All 32 of these locations were within 1 inch (2.54 cm) of the chime. A single through-hole was found – also at the tank perimeter. The corrosion of the tank bottom occurred primarily on the bottom-side of the plates (from the ground up); the top surface of the plates was observed to be relatively corrosion-free.

Epoxy coating

The tank utilises an internal epoxy coating applied only to the tank floor and bottom 10 ft (3 m) of the shell. The epoxy coating was mostly intact, but had failed around weld seams and a few other locations. No additional corrosion was observed in the areas where the coating had failed, leading to the conclusion that the coating is likely not providing much benefit.

Fig. 8 shows an overview of the tank chime (bottom corner).

Fig. 9 shows corrosion and scale under the tank chime.

Fig. 10 shows the typical interior shell/roof surface with a light coating of rust.

Fig. 11 shows typical tank floor surface with bottom-up corrosion near perimeter; boxes mark UT measurement locations.

Fig. 12 shows the tank shell measured thickness compared to nominal and minimum thickness; note single point of wall thinning at 0.08 ft (24 mm) elevation.

Corrosion mechanism

As can be deduced from the observations, the only significant concern revealed by the inspection was the corrosion of the tank floor occurring from the outside-in. The mechanism for this corrosion is thought to be water and sulphur making their way under the tank from the outside. The concrete pad on which the tank sits is a significantly larger diameter than the tank and does not slope away from the tank. Rain water that falls on the pad sits up against the chime and seeps under the tank. The water by itself is likely to cause some corrosion of the tank floor. But if sulphur were to mix with the water, the corrosion rate

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would be accelerated. The hot tank bottom would likely drive off some portion of the water, leaving a more concentrated water/sulphur mixture. This mixture is likely to form sulphuric acid and/or iron sulphide. In either case, accelerated corrosion would be expected. Sulphur is observed to condense around the tank vents and occasionally spill as a result of maintenance activities. Thus, some quantity of sulphur is typically observed on the concrete pad. There is high confidence that the corrosion mechanism described is accurate.

ControTrace heating system performance

The ControTrace heating system provides heat to the tank shell, roof, and vent nozzles. Of these surfaces, the only area that experienced corrosion was the bottom 1 inch of the tank shell. This result shows that the ControTrace heating system was effective at keeping the tank surfaces hot and preventing the corrosion mechanisms that had been experienced with previous sulphur tanks.

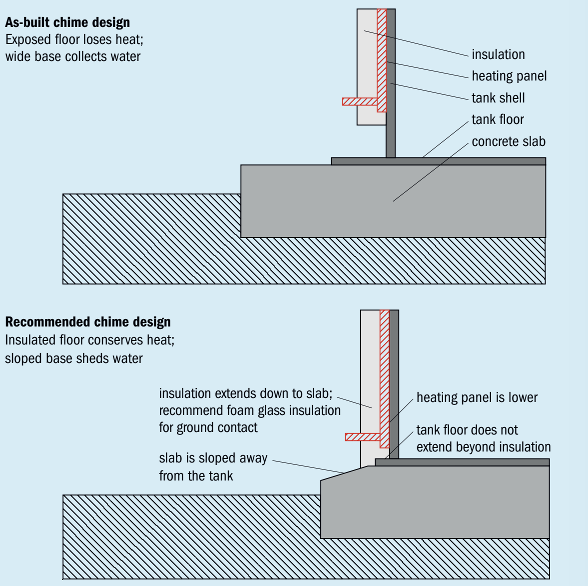
The corrosion on the bottom 1 inch of the shell is likely the result of three factors:

- The diameter of the tank bottom is roughly 12 inches (305 mm) larger than the tank shell. Thus the floor plates extend out beyond the tank shell and insulation forming a thermal ‘fin’ that draws heat away from the bottom corner of the tank.
- Water intrusion under the tank creates a significant heat load that also draws heat away from the bottom corner of the tank.
- The tank insulation does not extend all the way down to the floor of the tank. A small section of the tank shell is left exposed further lowering the shell temperature at the bottom corner of the tank.

Tank repairs

To address the tank floor corrosion, the petroleum company replaced the old 3/8" (10 mm) floor with a new 1/2" (13 mm) floor. The new floor is expected to provide a service life of roughly ten years at which time it is likely to need replaced again. Other minor findings were addressed including replacing the insulation, applying a new internal epoxy coating, and sealing the cracks observed in the concrete pad. It is expected that sloping the pad away from the tank and changing the design of the bottom corner of the tank would significantly reduce the rate of floor corrosion. But it was decided that the cost of such changes could not be justified on an existing tank.

Fig. 13: **Recommended changes to tank design to reduce floor corrosion**



Source: CSI

Comparison tank

A separate (second) sulphur tank was also commissioned in 2007, this one located at a separate gulf coast refinery owned by the same petroleum company. Similar to the (first) tank discussed, the petroleum company wanted to use an external heating system that would eliminate the internal coils and maintain the temperature of the shell and roof. To reduce cost, the petroleum company chose to use panel coils (or plate coils) to heat the second tank.

Panel coils are constructed from two plates that are stitched together to form a panel. Steam is applied to the space between the plates, and the assembly is attached to the exterior surface of the tank. Panel coils are practically limited to a rectangular profile; thus, they must be placed on the tank with considerable space between them to accommodate the tank roof geometry and to avoid nozzles. These gaps between the panels are large enough that the resulting tank surface temperature is non-uniform.

In 2017, the second sulphur tank was inspected in the same manner as the first. The detailed report was not made available for review, but the following repairs were necessitated due to extensive corrosion:

- the complete tank roof was replaced; roof corrosion was most prominent around the nozzles;
- two patches were required on the shell due to wall thinning;
- two patches were required on the floor due to wall thinning;
- an annular ring was installed on the floor to address wall thinning at the perimeter.

Both ControTrace and panel coils effectively maintain the liquid sulphur temperature. But only the ControTrace system maintains a uniform wall temperature distribution. Contrasting the first and second tank highlights the benefit of keeping the tank surface above the freezing point of sulphur at all locations.

Lessons learned

The petroleum company’s tank experience leads to several key lessons learned that can be applied to other sulphur tank applications:

- Maintaining the tank shell, roof, and vent nozzles above the freezing point of sulphur should be a high priority. Without adequate heat, plugging of the nozzles can result in hazardous H_2S build-up in the vapour space, and sulphur on the wall/roof surface can result in the formation of pyrophoric iron sulphides and rapid tank corrosion.
- The ControTrace tank heating system by CSI maintains a uniform temperature for the tank shell, roof, and vent nozzles. This approach can reliably prevent costly corrosion and the hazardous situations mentioned.
- The ControTrace tank heating system also effectively maintains the temperature of the liquid sulphur. While it was not discussed in detail, this sulphur tank included internal steam coils as a back-up heating system, but they were never used.
- The bottom corner of the tank is susceptible to corrosion due to a combination of heat loss and water/sulphur intrusion under the tank. Adopting some minor design changes to this area should reduce the corrosion rate significantly:
  - ○ Slope the concrete foundation away from the tank; this will help prevent water/sulphur from seeping under the floor.
  - ○ Design the tank chime area so that it does not protrude beyond the tank insulation; this will help maintain the temperature of the bottom corner.
  - ○ Extend the tank shell insulation all the way down to the foundation; this will help maintain the temperature of the bottom corner. Foam glass or other water-proof insulation should be used where the insulation meets the ground.
  - ○ Configure the tank vents and other equipment to minimise the amount of sulphur that drips on the concrete pad; this will help prevent sulphur from seeping under the floor. Minimising the diameter of the concrete foundation is one method of achieving this.

Fig. 13 provides a summary of the recommended changes to the tank design to reduce floor corrosion. ■

> **The ControTrace tank heating system maintains a uniform temperature for tank shell, roof and vent nozzles.**

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Acknowledgement

This article was presented at the Brimstone 2018 conference, Vail CO (Sep 2018).

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ISSUE 379
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Modern technologies for quality acid

Chemetics and NORAM discuss various strategies, equipment and processes that deal with cleaning the SO_2 gas feed to sulphuric acid plants, as well as product acid treatment to remove specific impurities.

Modern industrial production of sulphuric acid is based on the well-known contact process which involves the catalytic oxidation of sulphur dioxide (SO_2) to sulphur trioxide (SO_3) using a vanadium pentoxide (V_2O_5) based catalyst.

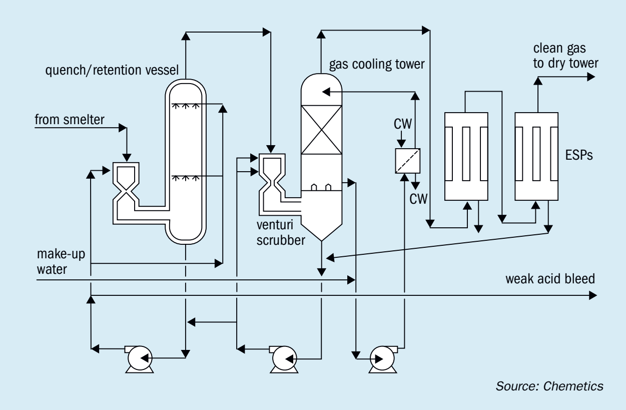
The SO_3 gas produced is then sent to absorption towers where a circulating stream of 98.5 wt-% sulphuric acid absorbs the SO_3 to form a stronger sulphuric acid solution. This acid is then diluted back to 98.5 wt-% H_2SO_4 by adding dilution water to the acid circulation system and results in a net production of product sulphuric acid.

From the above process description, it can be deduced that the product acid quality will be directly dependent on the following factors: (a) the amount of impurities in the feed SO_2 gas, (b) chemical analysis of the dilution water, and (c) the process equipment and piping that handles the sulphuric acid. In other words, any impurities contained in the feed SO_2 gas, dilution water, and corrosion of materials that handle the product, will end up in the product acid and potentially impact the stack emissions.

Gas cleaning in metallurgical off-gas sulphuric acid plants

For metallurgical smelters the SO_2 off-gas contains a wide variety of impurities such as SO_3, dust, (heavy) metals such as mercury, lead and arsenic, NOx, fluorides and chloride, etc. These impurities must be removed, or they will either end up in the product acid or causes fouling in the contact plant. Most commonly the off-gases from the smelter will be sent to a "wet" gas cleaning plant to cool and condense all the volatile gases, remove the dust, NOx, fluorides, etc. In most cases the gas cleaning system will need to be custom designed to match the feed gas impurities specifications. A typical gas cleaning system block diagram is shown below in Fig. 1.

Fig. 1: **Typical wet gas cleaning system**



Source: Chemetics

The hot gas from the smelter is first adiabatically cooled and volatiles will be condensed using a circulating flow of weak acid. After the quench step the gas is further cleaned using a venturi scrubber where most remaining solids are removed. Modern venturi scrubbers use a variable throat design which allows for adjustment of the pressure drop of the unit to maintain cleaning performance during variations of the gas flows from the smelter (Fig. 2). This allows the gas cleaning efficiency of the system be maintained over a wide range of operating conditions.

After the venturi scrubber the gas needs to be further cooled to condense excess water to maintain the water balance in the downstream sulphuric acid plant. For gas cooling service, historically this has been done with lead 'star' coolers, or by indirect cooling in packed or spray towers. Chemetics' wet gas condenser (WGC) provides significant advantages over both traditional approaches in both new and retrofit applications as the WGC can be a designed to simply replace an existing star cooler without any ducting modifications.

The WGC (Fig. 3) is a vertical shell-and-tube heat exchanger, where the process gas passes down through the tubes and cooling water flows on the shell side. As the gas is cooled, water and some contaminants condense on the tube walls and is drained from the bottom of the exchanger to a tank. A small amount of condensed liquid is pumped to the top of the WGC and distributed on the top tubesheet to continuously wash the tubes and remove any deposits. This eliminates most maintenance associated with solids deposits in the more traditional packed towers systems.

Fig. 2: Chemetics quench and scrubber venturi with variable throat design.

Fig. 3: Chemetics wet gas condenser.

The WGC is typically arranged with several units in parallel to match the number of wet electrostatic precipitators (WESPs). This provides redundancy and the ability to remove a WGC and WESP pair for cleaning or maintenance with a minimal reduction in overall capacity. In services with high water content or contaminant loads, a secondary set of WGCs in between the primary and secondary WESPs may be required.

NOx removal in product acid

Increasing NOx levels in smelter off-gases or sulphuric acid regeneration plants have become a serious issue for acid plant operators leading to problems with both stack emissions and product acid quality. The same applies to sulphur burning acid plants operating at very high furnace temperatures where more thermal NOx is produced.

In all cases a further complication is that high NOx levels make it difficult to safely carry out maintenance work as plant equipment contains NOx rich acid residues which can give off dangerous levels of NOx even after the plant has been purged and cooled as NOx fumes are released as the acidic residue is diluted (e.g. washing) or reacts with moisture in the ambient air.

Only a small portion, typically less than 10%, of the NOx in the gas is directly absorbed by the circulating acid in the absorbed towers. Instead most NOx is captured and concentrated in the acid mist collected in the absorber tower candles where the NOx is present as nitrosylsulphuric acid ($HNOSO_4$). Very high levels of nitrosylsulphuric acid can be present in the candles which can further cause problems due to its high freezing temperature. If freezing occurs the gas flow can be completely blocked with can cause equipment damage and serious impacts on the entire plant operation.

Because the NOx is predominantly captured in the drips from the candles it is important that these are segregated from the acid circuit for either disposal or further treatment, to avoid contaminating the product acid. The simplest approach for treating the candle drips is to simply dilute and neutralise the candle drips, but this creates an acid yield loss and an additional effluent from the acid plant. Care must also be taken during dilution as the rapid hydrolysis and the heat of dilution when the candle drips are mixed with water will result in the release of large quantities of NOx fumes. In most cases it will be necessary to use a scrubber to avoid the release of NOx into the atmosphere.

There are several techniques for treating the drips to remove the NOx content and return the sulphuric acid value into the acid circuit. One method[1] that has been used by Chemetics in several metallurgical acid plants takes advantage of the hydrolysis and heat of dilution to remove the NOx from the drips in a controlled fashion. The candle drips flow by gravity to a specially designed packed column, where they are mixed with water to dilute the acid. The $HNOSO_4$ is completely hydrolysed releasing the NOx which is vented from the top of the column. The nitrate free candle drips are then returned into the acid pump tank. The overhead NOx fumes either be vented to the stack or can be absorbed into water in a small stainless steel absorber system to form a weak HNO_3 effluent solution. The process consumes no reagents or power since the acid flows by gravity. The equipment is simple, reliable, and small (an 8-inch diameter packed column will treat the candle drips from a 2,000 short t/d acid plant).

It should be noted that achieving product acid NOx specification below 10 ppm may not be achievable if the NOx concentration in the gas is above 20 ppm even if the candle drips are segregated in this case the acid product must be chemically treated to reduce the NOx. Reduction can be accomplished by adding hydrazine, or sulphamic acid.

NOx destruction in the gas phase

An alternative method to reduce NOx in the product acid is to destroy NOx in the dry gas section of the contact plant. The use of selective catalytic reduction (SCR) allows the NOx removal reaction to take place at moderate temperatures (between 250-400°C) which makes it suitable to be incorporated into sulphuric acid plants where ideally it is placed between the cold exchanger and the inlet to the first catalyst bed.

The advantage of installing a DeNOx SCR system in the dry gas section of the contact plant are as follows:

- The gas is already within the required temperature range for the DeNOx catalyst.
- The gas is already very clean resulting in very low fouling of the DeNOx catalyst.

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SULPHUR
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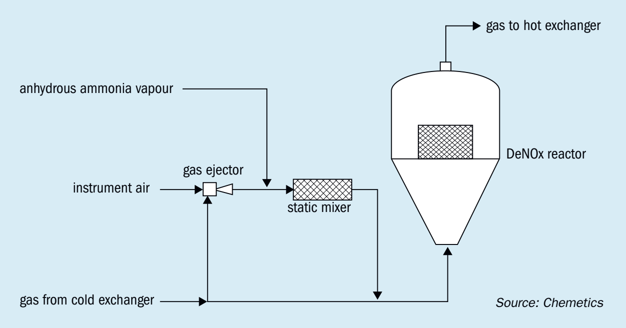
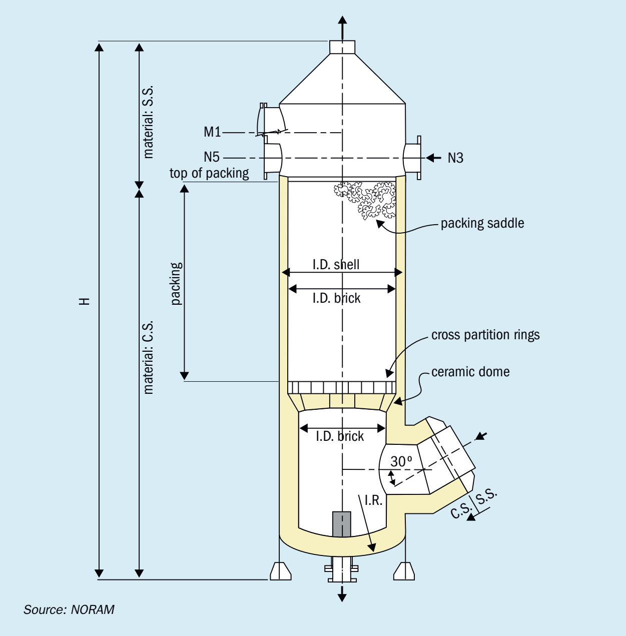
Fig. 4: **Schematic diagram of the SCR DeNOx process**



Source: Chemetics

Fig. 5: **NORAM SO_2 stripping tower**



Source: NORAM

- The NOx is destroyed early in the process before it encounters acidic residues where it can be absorbed to create later problems during maintenance.
- The NOx can be reduced to a level so that candle drip segregation is unlikely to be required and consequently eliminating the disposal or treatment problem.
- The NOx can be reduced to a very low level so that product treatment is not required and therefor eliminates the requirement to use potentially hazardous costly reagents.

The SCR process is performed using a reducing agent such as ammonia:

$6NO + 4NH_3 \rightarrow 5N_2 + 6H_2O$ (Reaction 1)

$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O$ (Reaction 2)

Any ammonia slip reacts with O_2:

$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$ (Reaction 3)

$4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$ (Reaction 4)

Fig. 4 shows a schematic diagram of the SCR DeNOx process. The main components of the SCR process consist of a reactor containing the catalyst and an ammonia storage and injection system. The ammonia can be in the form of water-free ammonia (preferred for acid plants), an aqueous ammonia solution, or a urea solution.

The ammonia is evaporated in an electrically, steam, or hot water heated evaporator and is subsequently diluted with air before the mixture is injected into the process gas duct. The injection of the ammonia/air takes place through a system of nozzles to achieve a uniform mixing of the ammonia with the process gas. A static mixer may be placed in the gas duct to further improve mixing. This mixing is important to ensure that the resulting gas-ammonia mixture has the uniform NH_3/NOx ratio required to ensure efficient removal of NOx and to minimise the NH_3 slip ("leakage") from the SCR reactor.

Based on reactions (1) and (2), the DeNOx reaction will result in a small increase in the moisture content of the gas stream. Any resultant dew point and mist considerations will need to be carefully assessed and addressed during detail design. In addition, based on reactions (3) and (4), any ammonia slip from the DeNOx System results in formation of new NOx as gas passes through the acid catalyst. Therefore, the design of the ammonia injection system, the SCR reactor and the control system are critical if high NOx reductions are required.

DeNOX SCR units to remove NOx in the feed gas to a sulphuric acid plant have been successfully implemented in two Chemetics designed sulphuric acid plants with a third one currently under construction. The first unit, zinc roaster processing zinc concentrate with high nitrogen content was commissioned in 1999 and has been operating since. The second unit, a lead/zinc smelter was started up in 2014 whereas the third plant will be starting in early 2019. These plants all use ammonia as the reducing agent. The DeNox systems are designed to achieve >95% NOx removal while operating with feed gas containing up to 300 ppm NOx. Designing for higher NOx content is possible but has not been required to date.

Reduction of SO_2 dissolved in sulphuric acid

SO_2 stripping towers can be used to remove any absorbed SO_2 from the product acid to meet commercial specifications, and to prevent SO_2 entrainment to the environment. Fig. 5 shows an example of a NORAM SO_2 strippers which can be brick-lined with a dished bottom for best mechanical strength (an option fabricated in NORAM SX™ alloy is also available).

Segregated pump tanks can also be used to prevent SO_2 from entering the product acid. The acid pumped around the last stage can be segregated before product acid is extracted. This can be done by using separate acid tanks for product acid loops or by separating a common tank with a barrier.

Reduction of solids entrained in sulphuric acid

Sulphuric acid circulation systems often suffer from issues caused by entrainment of solids into critical pieces of equipment. Solids can be entrained into the hot sulphuric acid circuits from a number of sources, including: construction debris, ceramic packing chips, breakage from brick-lined equipment, corrosion byproducts, and so on. If the solids are not contained, they are conveyed into the acid plant equipment with the acid circulation flow. This can cause plugging of the acid coolers, plugging acid distributors and erosion of equipment (pumps, piping, valves and vessels). Hot acid strainers can be used to remove solid particles from hot sulphuric acid. Fig. 6 shows an example of a NORAM acid strainer.

PHOTO: NORAM

Fig. 6: NORAM SX™ Chip Guard CG™ in-line strainer.

PHOTO: NORAM

Fig. 7: NORAM SX™ alloy acid towers.

Reduction of metals dissolved in sulphuric acid

Use of corrosion resistant alloys and improved designs can reduce corrosion. Fig. 7 shows examples of NORAM SX™ alloy acid towers. Reduced corrosion minimises the formation of metal sulphates that could enter sulphuric acid product. The content of metals such as Fe in the product acid can also be reduced.

Conclusions

As smelting technology continues to evolve, and more complex ores need to be processed, smelter off-gas impurities levels will continue to increase. This will impact the product acid quality as well as stack emissions in the sulphuric acid plant.

Applying modern wet gas cleaning technologies will increase the amount of impurities being captured before they reach the contact section of the acid plant. This will improve the product acid quality as well as increase reliability of the acid plant.

Currently post treatment techniques are available by which NOx in the product acid and the stack gas can be controlled. In addition, DeNOx SCR technology is a proven process to destroy NOx in the gas before it enters the SO_2 oxidation catalyst, with the added benefit of eliminating the need for post product acid treatment.

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PHOTO: WOOD

Electric reheaters installed in a revamped SRU to replace an underperforming hot gas bypass system (upper part of reheaters visible above platform).

SRU marginal investment for tangible benefits

Recent SRU revamp projects from Fluor, RATE, Wood and Jacobs demonstrate that marginal investment for the upgrade, modernisation or revamp of sulphur recovery units can result in significant benefits.

In today's competitive oil and gas market, many refiners are proceeding to revamp their facilities to process heavier, sour crude oil feedstocks and meet continuously tightening environmental regulations for transportation fuels. This leads to increased use of hydroprocessing to recover more sulphur in the form of hydrogen sulphide (H_2S) from the crude oil and ultimately higher processing loads to the downstream sulphur recovery unit (SRU). Capacity enhancement to handle these higher loads is typically achieved by installation of additional SRU trains or the implementation of oxygen enrichment technology into existing SRU trains. Another recent trend has been to expand capacity to achieve greater SRU availability and reliability.

Revamps or modernisation projects can be categorised according to the purpose of the improvements:

- for additional capacity, e.g. using 25-100 % oxygen enrichment or other capacity expansion options e.g. using a 2-stage SWS;
- to reduce stack SO_2 emissions to meet new environmental regulations;
- to improve the control systems, new burner management systems and to improve the reliability and safety of the unit;
- to change fired reheaters to steam reheaters, RGG inline burner to steam reheater, to upgrade the refractory, SRU and TGU catalysts and to upgrade the amine type in the TGTU;
- for higher or lower turndown due to change in feed compositions and capacity;
- to process ammonia acid gas in addition to amine acid gas;
- to recycle pit vents from degassing and sulphur storage or to add an additional vent e.g. SO_2 from other units;
- to add a tail gas treating unit;
- to add sulphur degassing;
- for energy optimisation, to reduce fuel gas consumption in incineration, or to add heat recovery and to optimise the consumption of utilities.

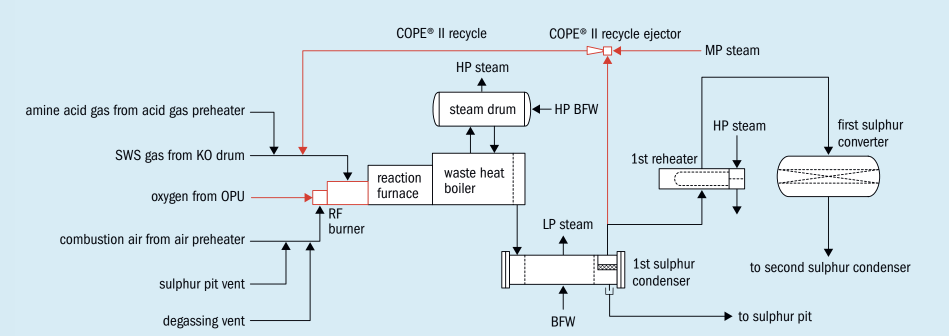
In general, it is well known that in most cases modifications or the modernisation of existing sulphur recovery units will have a lower capital cost and require less investment than the construction of a new unit. However, it is essential that, depending on the nature of the modifications, a technical evaluation should be conducted based on a detailed cost estimate so that the benefits and savings for the options considered can be compared. In some cases plot space limitations and operating costs can play a major role in the decision making process. ■

FLUOR ENERGY & CHEMICALS, INC.

Reliable SRU capacity enhancement with COPE® II

Brian Jung, Theresa Flood, Thomas K. Chow

Fig. 1: **COPE® II SRU thermal stage**



Source: Fluor

With the oil and gas industry more competitive than ever, it is crucial that refiners utilise cost-effective, commercially-proven technologies to capacity enhance their SRUs and meet increasingly stringent environmental regulations. Due to the minimal changes to existing equipment, Fluor/GAA's COPE® II technology can be implemented quickly and is a highly cost-competitive method to increase SRU availability and reliability. Over 50 operating plants currently use Fluor/GAA COPE® technology.

This article discusses oxygen enrichment technology, the Fluor-owned Goar, Allison, & Associates (GAA) Claus Oxygen-based Process Expansion II (COPE® II) process and the implementation of COPE® II technology in two recent projects.

Oxygen enrichment and COPE® II process description

In the modified Claus process, H_2S in the acid gas feed stream(s) is converted to elemental sulphur thermally and catalytically based on the following primary reactions:

$$H_2S + 3/2O_2 \rightarrow SO_2 + H_2O \quad \text{(thermal)}$$

$$2H_2S + SO_2 \rightleftharpoons 3S + 2H_2O \quad \text{(thermal and catalytic)}$$

$$3H_2S + 3/2O_2 \rightleftharpoons 3S + 3H_2O \quad \text{(overall)}$$

The thermal reaction converts approximately 60-70% of the H_2S to elemental sulphur in the reaction furnace (RF), which operates between 1,090°C and 1,400°C for typical refinery acid gases if the oxygen for the thermal reaction is provided from combustion air. The catalytic reaction occurs in the downstream sulphur converters at much lower temperatures. The sulphur vapour produced by the thermal and catalytic reactions is condensed by the sulphur condensers. Notice that nitrogen does not participate in the Claus reactions.

Since the SRU operates at close to atmospheric pressure, its ultimate capacity is hydraulically bottlenecked by the maximum SRU inlet battery limit pressure or combustion air blower shut-off pressure. Oxygen enrichment can increase the capacity of SRUs with minimal capital investment by utilising enriched air, which has higher oxygen content than combustion air, as the oxygen source for the thermal reaction. In an air-blown SRU, a significant portion of the volumetric process gas flow is inert nitrogen that is introduced as part of the combustion air. With less inert nitrogen in an oxygen-enriched SRU, the system pressure drop is lower, allowing more acid gas to be processed. One consequence of oxygen enrichment is a hotter temperature in the reaction furnace. This is beneficial for ensuring ammonia destruction. Commercially available refractory materials are tested for operation up to 1,540°C in a reducing environment, with material limits between 1,650°C and 1,760°C in an oxidising environment. However, most companies prefer to limit reaction furnace operating temperatures between 1,310°C and 1,480°C. This maximum operating temperature limits the extent of processing capacity enhancement, particularly for rich acid gases with high level oxygen enrichment (> 45%), unless special temperature moderation technology is utilised.

The Fluor/GAA process is a patented, commercially proven temperature moderation technology developed to enhance the capacity of an existing SRU with high level oxygen enrichment while maintaining the Reaction Furnace temperature below refractory material limits. The main differences between an air-blown SRU and a COPE® II SRU can be found in the thermal stage, which includes the RF burner, reaction furnace, waste heat boiler, and first sulphur condenser. Fig. 1 is a sketch of the thermal stage of a SRU with the new COPE® II equipment and piping highlighted in red.

As shown in Fig. 1, with the implementation of COPE® II, a new COPE® II RF burner with a dedicated nozzle for high purity (usually 90+ vol-%) oxygen is required. In addition, a steam ejector is required to recycle a portion of the cooled process gas exiting the first sulphur condenser to the RF burner inlet for temperature moderation.

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This COPE® II recycle ejector is simple to operate and the recycle rate can be easily adjusted based on the oxygen enrichment level required. The reaction furnace can typically be reused because operation at higher temperature increases reaction kinetics and reduces required residence time. Evaluation is required for the waste heater boiler and first sulphur condenser on each project. Other SRU equipment can typically be reused because the operating parameters are similar between combustion air and oxygen-enrichment operations.

Tail gas treating and increasingly stringent regulations

The conversion of H_2S to elemental sulphur in a modified Claus SRU is reaction equilibrium limited and overall sulphur recovery is limited to 93-96% for 2-stage and 95 to 98% for 3-stage Claus trains without additional tail gas treating.

In most locations, present day environmental regulations do not permit the discharge to atmosphere of SRU tail gas since it typically contains 2-7% of the total sulphur in the SRU feed. The SRU tail gas consists mainly of H_2S, sulphur dioxide (SO_2), and sulphur vapour. Carbonyl sulphide (COS) and carbon disulphide (CS_2) from secondary reactions may also be present in the tail gas. These are generally low for refinery feedstocks, but may be at significant levels for gas plants and gasifier effluent feedstocks. A hydrogenation-amine type tail gas treating unit (TGTU) removes the sulphur in the SRU tail gas such that 0.1% or less of the feed sulphur is emitted to atmosphere. The sulphur components in the tail gas are first reduced to H_2S in a CoMo hydrogenation reactor and then the H_2S is removed by an amine solvent. The H_2S removed from the tail gas is recycled to the front of the SRU to improve overall sulphur recovery. The CoMo hydrogenation reactor effluent is hot and contains a significant amount of water vapour, mainly formed as a Claus reaction byproduct. For effective H_2S removal in the downstream amine absorber, the tail gas must be cooled. Excess water is removed as the gas is cooled, reducing the volumetric throughput. This occurs in the reactor effluent cooler and quench tower.

Implementation of COPE® II in recent projects

Fluor/GAA's COPE® II technology has been implemented on two recent projects as discussed below.

Project 1 description

The first SRU revamp project discussed is for an undisclosed client located in the EMEA region. The refinery contains two SRU trains built in 2005, with a third train added subsequently. The existing sulphur processing capacity for each train is 70 t/d, for a total capacity of 210 t/d. The acid gas feedstock includes both a rich (80 to 90 mol-% H_2S) acid gas and sour water stripper acid gas. The main objectives of the project are to implement hydrogenation-amine tail gas treating for increased recovery and oxygen enrichment for spare train availability. Under normal circumstances, the three trains operate with combustion air only at 70 t/d each. After project completion, if one train were to shut down, the remaining two trains would operate with oxygen enrichment at 105 t/d to process a total of 210 t/d and avoid any impact to the upstream refinery units. The selected configuration includes Fluor/GAA's COPE® II technology using 52% oxygen enrichment, Fluor's TGT technology using ExxonMobil Flexsorb® SE Plus solvent, and Fluor/GAA's D'GAASS® sulphur degassing technology.

The following were requirements and limitations pertinent to the project scope/execution:

- reaction furnace operating temperature limit of approximately 1,340°C (desired by client);
- emission limit of 400 mg/Nm^3 or less SO_2 in the thermal oxidiser stack;
- minimum 99.98% overall sulphur recovery;
- high ambient temperature;
- minimise footprint due to limited plot space;
- minimise capital and operating expenditure (capex and opex).

It should be noted that installation of a new fourth SRU train would have yielded spare train capacity, but oxygen enrichment was selected as the path forward due to the limited plot space and the additional capex associated with a new train. To stay below the reaction furnace temperature limit, the COPE® II process was also implemented in this project.

In addition, the existing facility does not have any operating tail gas treating. In order to satisfy the emissions requirement of 99.98% overall sulphur recovery, a hydrogenation-amine type TGTU was included in the scope.

The following modifications are part of the project:

- TGTU: Installation of a new hydrogenation-Flexsorb® TGTU for each SRU train with common solvent regeneration to satisfy the emission requirement of 99.98% overall sulphur recovery.
- RF Burner: Replacement of the existing burner with a COPE® II burner which is designed for both air only and high level oxygen enrichment operation.
- Oxygen production unit (OPU): Installation of a new vacuum pressure swing adsorption (VPSA) OPU to produce high purity (90+ vol-%) oxygen supply and installation of oxygen control instrumentation.
- COPE® II recycle ejector: Installation of a new COPE® II recycle ejector and controls for reaction furnace temperature moderation during oxygen enrichment.
- Combustion air blower – Replace or modify the existing combustion air blowers to increase head to overcome the greater system pressure drop caused by the installation of the TGTU.
- First sulphur condenser: Replace the existing first sulphur condenser to accommodate the higher duty required during oxygen enrichment operation.
- Waste heat boiler (WHB): At this site, no modifications of the WHB are required due to sufficient exchanger surface area in the existing design and due to the low heat flux values used in the original design. Instead, some duty is shifted into the new first sulphur condenser.
- High pressure (HP) steam drum – Replace the HP steam drum to accommodate the increased HP steam production during oxygen enrichment.

Project 1 summary

An economic analysis was performed to compare the capex and opex savings associated with the implementation of Fluor/GAA's COPE® II technology in Tables 1 and 2. Case 1 represents the installation of a fourth SRU train to attain the desired spare capacity while Case 2 represents the implementation of COPE® II to the existing three SRU trains.

Table 1: **Project 1 capex comparison**

	Case 1: 4th train	Case 2: COPE® II
Capex	base	-79%
Capex incl. OPU	base	-66%

Source: Fluor

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Table 2: **Project 1 opex comparison**

	Case 1: 4th train	Case 2: COPE® II
HP steam production	base	+3%
LP steam production	base	+7%
Power consumption	base	-43%
Fuel gas consumption	base	-76%
Cooling water consumption	base	-23%

Source: Fluor

As shown in Table 1, use of Fluor/GAA's COPE® II oxygen enrichment with a new OPU is estimated to have reduced capex by 66% compared to installation of a new 70 TPD SRU/TGTU train, even if installation of a new train were feasible in the limited adjacent plot space. In addition, significant opex savings are estimated as summarised in Table 2.

Project 2 description

The second project is for a refinery located in the U.S. with two identical SRU trains each originally designed for a sulphur processing capacity of 225 long t/d with combustion air and 360 long t/d capacity using 32% oxygen enrichment. The SRU/TGTU trains were constructed in 2008 for an undisclosed client. The existing configuration includes 3-stage Claus followed by a hydrogenation-amine TGTU using generic MDEA. Both a rich acid gas and ammonia-laden sour water stripper acid gases are processed. Initially, the main objective of the project was to improve the reliability of the thermal stage as the client had experienced numerous unscheduled outages with the existing equipment. During the initial phase of the project, however, the project team identified the opportunity to enhance processing capacity up to 440 long t/d by implementing 60% oxygen enrichment with the Fluor/GAA COPE® II process. A separate project adds Fluor/GAA's D'GAASS® out-of-pit liquid sulphur degassing facility to minimise the risk of personnel exposure to H_2S during loading and transportation of product sulphur.

The requirements and limitations pertinent to the project scope/execution were as follows:

- Reaction furnace operating temperature limit of approximately 1,430°C (desired by client)
- Emission limit of 50 ppmv SO_2 in the thermal oxidiser stack
- Minimise footprint due to limited plot space
- Minimise capital and operating expenditure (capex and opex)
- Includes automated ramping of oxygen and temperature moderation controls as enrichment level increases, with corresponding automated decreases as operation returns to air only mode.

Fluor's evaluation determined that the existing two-pass WHB design was not a reliable design; high stresses along the tube-sheet and insufficient BFW circulation likely caused the numerous train outages. Replacement of the WHB is a key factor in achieving the Client's reliability goals.

To minimise capex and footprint, the existing first sulphur condenser was reused. However, this equipment item became the train bottleneck, limiting the capacity expansion to 440 long t/d.

The following modifications are part of the project:

- RF burner, reaction furnace, waste heat boiler: Replacement of the existing thermal stage (excluding the first sulphur condenser) for reliability and to accommodate the expanded acid gas throughput via the COPE® II process.
- COPE® II recycle ejector: Installation of a new COPE® II recycle ejector for reaction furnace temperature moderation during oxygen enrichment.
- Amine acid gas KO drum: Specification of new internals to handle the higher amine acid gas flow.
- TGTU quench tower (contact condenser) air cooler: Installation of a third bay to handle the increased quench duty, allowing for removal of the additional water formed by the Claus reaction of additional acid gases.
- Oxygen system: Modification of oxygen controls to the RF burner of the reaction furnace to allow for additional oxygen usage. Note that the oxygen supply for this site is via pipeline and does not require modification.

Project 2 Summary

Tables 3 and 4 summarise the relative capex and opex values between installation of a new 80 long t/d SRU train (Case 1) and implementation of COPE® II technology (Case 2) to achieve a total sulphur processing capacity of 440 long t/d.

This project is able to realise substantial capacity expansion benefits from marginal capex investment, while at the same time eradicating an existing reliability concern. It is estimated that implementation of COPE® II technology reduced the capex by 82% compared to installation of a new 80 long t/d SRU train. In comparison to Project 1, this project had additional capex savings due to the high purity oxygen being supplied via pipeline. ■

Table 3: **Project 2 capex comparison**

	Case 1: Additional new train	Case 2: COPE® II
Capex	base	-82%

Source: Fluor

Table 4: **Project 2 opex comparison**

	Case 1: Additional new train	Case 2: COPE® II
HP steam production	base	-3%
LP steam production	base	+7%
Power consumption	base	-70%
Fuel gas consumption	base	-81%
Cooling water consumption	base	-19%

Source: Fluor

RAMESHNI & ASSOCIATES TECHNOLOGY & ENGINEERING (RATE) USA

Revamping for additional capacity in a CIS refinery

Mahin Rameshni

Rameshni & Associates Technology & Engineering (RATE) USA recently conducted a study for a refinery modification in the CIS region. The refinery has two existing sulphur recovery units, each with a capacity of 75 t/d, providing a total SRU capacity of 150 t/d. The refinery would like to expand the capacity of the SRUs to process additional amine acid gas and ammonia acid gas resulting from a refinery expansion, which included the addition of a new hydrotreater as well as other units. Five options were considered in the feasibility study:

- **Option 1:** Modify each SRU using high level oxygen enrichment to double the capacity of the original units (due to space limitations, a 2-pass WHB design is used).
- **Option 2:** Modify the SRUs by adding a common section, comprising a new burner, reaction furnace and waste boiler operating with oxygen under normal operation and providing 150% capacity to each existing train (due to space limitations, a 2-pass WHB is used).
- **Option 3:** Add a new sulphur recovery unit to handle the new additional capacity.
- **Option 4:** Build a new SRU for the total capacity.
- **Option 5:** Modify the existing SRUs and use a 2-stage SWS design.

The final report was submitted to the customer in August 2018. The detailed cost estimate cannot be released due to confidentiality but the summary is described below. It is important to mention that the lowest cost option may not be the best choice and other factors like operating costs, logistics, and space limitation had to be taken into consideration.

Study conclusions

Options 1 and 2 are well known configurations using high level oxygen enrichment, staged combustion for each train separately or a common new unit to serve both trains, resulting in a lower capital cost compared to building a new SRU unit. Option 2 would have a lower capital cost than option 1. Although there is some oxygen available at the refinery, the customer preference was not to use oxygen enrichment due to the high cost of buying oxygen on a regular basis, resulting in high operating costs and logistics concerns.

Options 3 and 4 involve building a new sulphur plant either based on additional future capacity or to handle all of the amine acid gas and all of the SWS gas. These options, however, are the most expensive and require a large plot space. In addition, the refinery had difficulty in making the decision on whether to size the new unit for the additional capacity only or for both existing and future capacity to handle both amine acid gas and the ammonia SWS gas.

In option 5 a 2-stage sour water stripper is used to separate the H_2S from ammonia. All current and future H_2S would be processed in two existing SRUs with necessary modifications to allow the existing units to operate with air only and all the ammonia would be burned in a special incineration system designed for burning ammonia. The existing SWS can be modified to the proprietary RATE 2-stage SWS design, minimum modifications are required to the existing SRUs and the incinerator would be upgraded to ammonia burning incineration.

The capital cost of option 5 is much lower than options 3 and 4 and comparable to options 1 and 2 (considering lower opex by eliminating the cost of oxygen). Option 5 was selected as the best option for the customer.

RATE has already licensed several 2-stage SWS designs which are in operation in the CIS region.

Preparation of the license package for this project will be carried out by RATE, with the detailed design and construction carried out by others that will be started in the coming months.

Option 5 proposed scheme

In option 5, no ammonia SWS gas is sent to the existing SRUs. The sulphur recovery units will be modified to handle additional sulphur and amine acid gas. In the existing SRU, the air blower may need to be modified to handle more capacity without using oxygen.

The existing sour water stripper can be modified to the 2-stage SWS design by the addition of a tower. The H_2S absorber is added to increase the ammonia purity and to prevent ammonia going to the SRU. Otherwise other processes would be required to handle the ammonia.

The incineration system can be modified to have ammonia burning capability. In the RATE 2-stage SWS design, H_2S is separated from ammonia and the ammonia is sent to an incinerator. Special ultra-low NOx burners, a waste heat boiler and air blower are required to burn the ammonia in the incinerator without causing emission problems. This option is popular when the existing SRU cannot handle an additional load of gas.

RATE 2-stage SWS design

Figs 1 and 2 show the RATE 2-stage SWS design.

H_2S stripping

From the feed tank, the degassed sour water is pumped to the 2-stage SWS plant, where it is heated by feed bottoms exchange and fed to the acid gas or hydrogen sulphide stripper. This stripper is a steam-reboiled distillation column. The hydrogen sulphide, which is stripped overhead, is of high purity and is an excellent feed for sulphur plants. It contains negligible ammonia and, because the plant feed has been degassed, contains only traces of hydrocarbons. It does, however, contain any carbon dioxide that is present in the feed.

Ammonia stripping

The hydrogen sulphide stripper bottoms stream, containing all the ammonia in the feed and some hydrogen sulphide, is fed directly to the ammonia stripper, which is a refluxed distillation column. In this column, essentially all ammonia and hydrogen sulphide are removed from the water, which leaves as the column bottoms stream. After exchanging heat with the hydrogen sulphide stripper feed, this stripped water is cooled and sent off-plot for reuse or treating. The ammonia and hydrogen sulphide stripped from the water in the ammonia stripper are passed through an overhead condenser and are partially condensed.

H_2S absorption

The purpose of the H_2S absorber is to remove any additional H_2S from the rich NH_3

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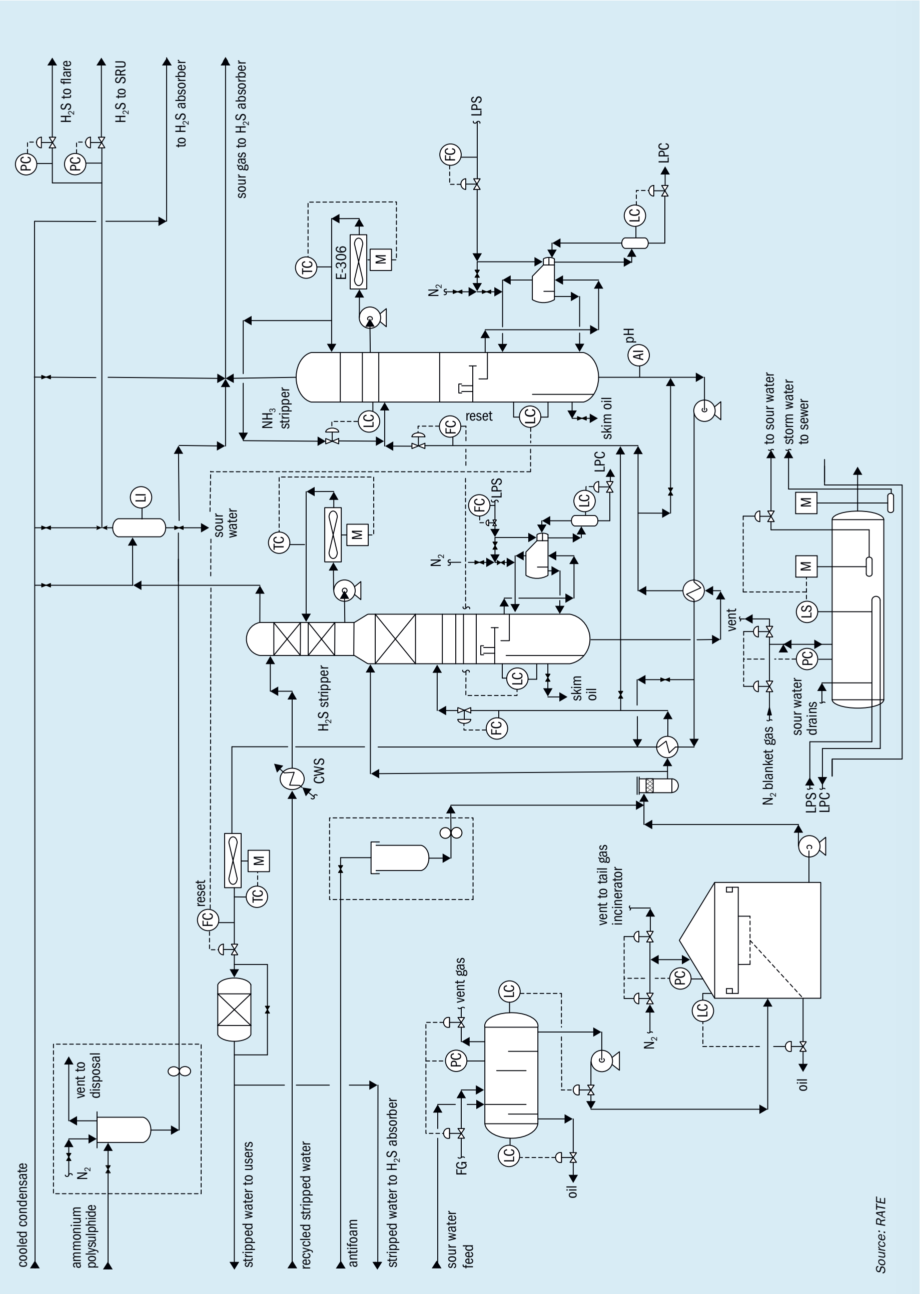

Source: RATE

Fig. 1: Two-stage SWS proprietary design by RATE

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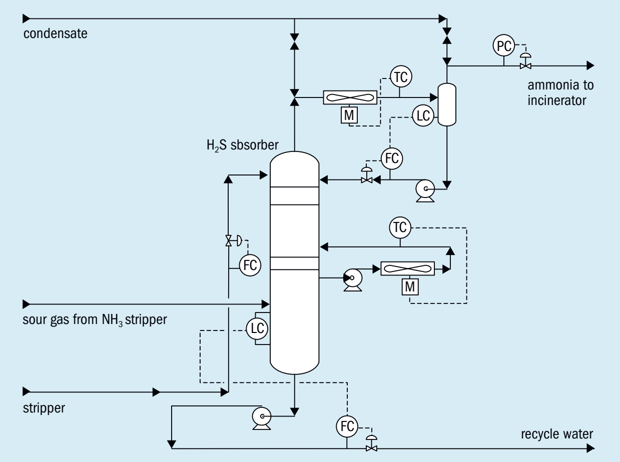
Fig. 2: **Two-stage SWS proprietary design by RATE continued**



Source: RATE

stream and recycle it back to the system. The SO_2 emissions from the incineration stack are in accordance with regulations.

Ammonia recovery or incineration

Ammonia can be sold as a liquid to local fertilizer companies or burned in the incineration system.

For some plants, ammonia recovery may not be desired or economical. In such cases, the ammonia product may be incinerated, either directly off the reflux drum or after being scrubbed with water to reduce the H_2S content. Alternatively it may be further purified and recovered to produce either anhydrous or aqueous ammonia suitable for sale or for further processing.

In the first distillation column, the H_2S-NH_3 mixture is stripped to obtain a H_2S-rich vapour which flows to the sulphur recovery unit. The bottom of the stripping column contains an NH_3-rich stream which flows to the second tower.

In the second distillation column the rich NH_3 stream is stripped to obtain an NH_3-rich vapour which is purified further in the H_2S absorber to remove any residual of H_2S before sending it to the ammonia burning incinerator or to the fertilizer unit.

The overhead of the H_2S absorber via the knockout drum is a pure rich NH_3 stream. The bottom of the H_2S absorber and the knockout drum containing H_2S will be recycled to the first distillation tower (H_2S stripper) via the feed tank.

The advantage of the 2-stage column design is the separation of H_2S and NH_3 into different product streams. The ammonia stream can be combusted without producing significant SO_2, or it can be purified and sold as feedstock. Likewise the purified H_2S can be used directly as a feedstock for a sulphuric acid plant. Besides the beneficial uses, diverting ammonia away from the sulphur recovery unit can improve SRU performance. Ammonia can cause operating problems such as catalyst deactivation and equipment plugging in the SRU. In addition, a higher flame temperature is required to fully destroy NH_3, leading to higher COS and CS_2 formation and subsequently lower sulphur recoveries. The size of the SRU can be reduced or the throughput of an existing unit can be increased since the extra air required to burn the ammonia, as well as the ammonia itself, is eliminated from the feed.

The incineration section consists of a forced draft incinerator with heat recovery. The burner is a proprietary design to handle ammonia incineration without any NOx formation.

The flue gas is cooled in a waste heat boiler by generating high-pressure steam. The high-pressure steam along with the excess high-pressure steam from the SRU is superheated in the superheater coil of the incinerator waste heat boiler before export to the high-pressure steam header. The incinerated flue gas is routed to the stack. ■

WOOD

Recent refinery revamp and modernisation projects in the US

Scott Kafesjian, Nick Watts

Wood's sulphur technology experts have studied and developed revamp and modernisation designs for several sulphur recovery units. Reported here are highlights of several recent revamp projects that have enabled improved operation, reduced operating costs, increased capacity, and/or reduced atmospheric SO_2 emissions.

The scope of each project was developed by Wood's sulphur experts, after reviewing operating information, design documents, evaluating and checking various alternative revamp approaches, and coordinating efforts with client engineers.

Refinery A

A US refinery in the Rocky Mountain region was unable to process sour water stripper (SWS) off-gas in their SRU. The original unit was designed to be operated with a front/rear split of amine acid gas, with all of the SWS gas and a portion of the amine acid gas fed to the burner. A checker wall was present in the thermal reactor. Two acid gas inlet ports were present just downstream of the checker wall, on opposite sides of the thermal reactor.

Despite repeated attempts to feed SWS gas and create proper operating conditions to destroy the ammonia present, extended run time could not be realised. Unit pressure drop would rapidly build up and force the unit to be shutdown. Run length with SWS gas feed was limited to hours or days.

Wood's sulphur technology experts were contacted to troubleshoot the problem and recommend a solution. After reviewing equipment information and operating data, Wood concluded that there were several problems with the existing SRU:

- the existing burner did not provide the intense mixing needed to ensure good ammonia destruction;
- piping, instrumentation, and controls were inadequate to ensure the front-side split of amine acid gas flow was correct;
- accuracy of temperature instruments in the thermal reactor was poor.

The upgraded design included a proprietary Wood acid gas burner, improved metering and flow controls for acid gas and SWS gas feeds, improved air metering and control, a new high energy pilot, and revised refractory and burner tiles to match the Wood burner design.

As a result of the revamp and upgrades, the unit has been able to process SWS gas and achieve excellent ammonia destruction (reported as 62 ppmv in a performance test), enabling continuous unit operation without shutdowns due to salt formation and plugging.

Table 1: **Refinery D SRU/TGTU performance test results**

	Guarantee/permitted	Measured
Acid gas capacity, long t/d of sulphur	185	156*
SRU once-through sulphur recovery efficiency, %	96	96.35
SO_2 in TGTU incinerator stack, ppmvd @ 0% O_2	250	71.7

Source: Wood

*max available feed rate

Refinery B

Another northern US refinery was required, due to a consent decree, to install a tail gas treating unit (TGTU) to improve sulphur recovery efficiency and reduce SO_2 emissions. The tail gas streams from two existing Claus SRUs, one 2-reactor unit and one 3-reactor unit, were to be fed to the new TGTU.

Analysis of plant material balances revealed that the typical recovery efficiency of the existing SRUs was poor, ranging from 88-92%. The units were also plagued by catalytic reactor operating difficulties and poor temperature control of the reactor inlet streams. Lack of a rich amine flash drum resulted in higher than desired hydrocarbon level in the acid gas feed. Based on Wood's study and analysis of process simulations, the major factors contributing to low recovery were the hot gas bypass reheat method, and the poor control of reactor inlet temperature. Hydrocarbons in the feed also impacted the recovery to a lesser degree.

Wood's proposed solution included decommissioning the hot gas bypass system and installing electric reheaters for each reactor inlet (Fig. 1). With optimised temperature control and removal of the hot gas bypass system, recovery was expected to increase to about 95-96%. A rich amine flash drum was also added as part of the project.

Fig. 1: Electric reheaters (upper part visible above platform) installed in revamped SRU.

As a result of the improved recovery efficiency in the SRU, the TGTU could be designed for lower inlet sulphur, resulting in reduced capex and opex.

Refinery C

Anticipating the need for increased sulphur recovery unit and tail gas treating unit capacity for processing an increasing sour water stripper acid gas load resulting from an increasing crude slate nitrogen content, and desiring increased operating reliability, a US refiner contracted with Wood's sulphur technology group to modernise and debottleneck a 1990s vintage Claus SRU and amine based TGTU. Reduced atmospheric SO_2 emissions were required due to a consent decree from regulatory authorities. The project resulted in an increase of over 57% in the air-based nominal sulphur capacity, with SO_2 emissions reduced from 250 ppmv to less than 125 ppmvd @ 0% O_2.

The project scope included modernising the unit flow sheet to provide a high pressure (600 psig) SRU waste heat steam generator and corresponding inter-stage reheaters. The HP steam reheaters provided improved reactor inlet temperature control and allowed the removal of an indirect fired reheater and two gas-gas heat exchangers. Additionally, significant pressure drop reduction was realised by revising the main process piping from the waste heat boiler to the first condenser, from the sulphur condensers to the reheaters, reactors, and back to the condensers.

Replacement and upgrade of the acid gas burner with a Wood proprietary burner and thermal reactor, with associated instrumentation and controls, was made. The study also identified the combustion air blowers and the first sulphur condenser to be bottlenecks, therefore these items were also slated for replacement.

In the tail gas unit, the tail gas quench tower and absorber capacities were increased by replacing existing conventional trays with high-capacity trays. Low-temperature catalyst was specified in the tail gas reactor to permit reduction in operating temperature and reduce energy consumption. To reduce SO_2 emissions and contribute to capacity improvement, the standard MDEA tail gas solvent was replaced with formulated MDEA.

Performance testing confirmed the improved performance, documenting 97.9% recovery in the Claus section and over 99.99% overall sulphur recovery efficiency, and stack SO_2 of less than 60 ppmv. Ammonia at the thermal reactor outlet was undetectable (the analytical method was stated to have a 25 ppmv measurement threshold).

Refinery D

To comply with state regulations mandating the elimination of acid gas flaring, a US Gulf Coast refiner contracted with Wood's sulphur technology group for the turnkey upgrading and debottlenecking of an existing 2-stage Claus SRU train and the installation of a new parallel, redundant Claus SRU train. The scope of the project included adding a third catalytic stage to the existing SRU train and increasing its nominal capacity from 150 to 185 long t/d. The design capacity of the new 3-stage SRU train was 200 long t/d.

The upgrading and debottlenecking of the existing SRU train included replacing

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the existing combustion air blowers, replacing the burner with a proprietary Wood acid gas burner and new pilot, acid gas and combustion air flow control instrumentation and valves, and SRU waste heat steam generator and inter-stage reheaters. A third catalytic stage was added, including a new HP steam reheater, catalytic reactor, and sulphur condenser. The existing sulphur condenser was reconfigured from a 3-pass to a 2-pass unit. A new 2-pass sulphur condenser was added, housing the 3rd pass relocated from the existing condenser and the 4th pass for the new 3rd catalytic reactor outlet.

Finally, the sulphur rundown and collection system of the existing SRU train was replaced with above-ground sulphur seal valves draining into an above-ground sulphur collection header. Sulphur collected in the header was pumped to a sulphur storage tank, common with the new SRU train. This system replaced conventional hydraulic sulphur seals and a below grade concrete sulphur pit. For SRU over-pressure protection, piping was added from the outlet of the no. 1 reheater to the incinerator, with a rupture disk holding against the SRU normal operating pressure. The rupture disk was located at the high point of the process piping, fully steam traced, and the outlet line to the incinerator was steam traced and free-draining.

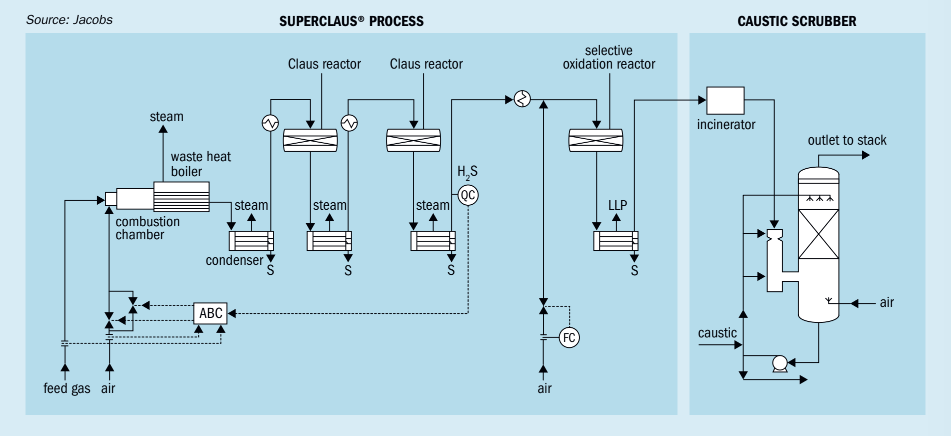
The SRU/TGTU performance test results (Table 1) demonstrate that the revamped SRU train met the guaranteed and permitted performance criteria. ■

JACOBS COMPRIMO® SULFUR SOLUTIONS

The SUPERCLAUS®/Scrubber process

Marco van Son

Fig. 1: **SUPERCLAUS®/caustic scrubber combination**



Source: Jacobs

As regulators worldwide are mandating higher sulphur recoveries in the refining, gas processing and chemical industries in a very competitive market with fluctuating oil prices, options for meeting these requirements at lower costs, both capital and operating, are becoming more important. The traditional method for increasing the overall recovery efficiency of sulphur recovery units has been the installation of an amine-based tail gas treatment unit (TGTU), which is a well proven and reliable technology, but requires substantial capital investment. As an alternative, Jacobs offers a combination of its SUPERCLAUS® technology with a proprietary caustic scrubber design to meet higher sulphur removal potential at lower capital cost. A simplified process flow diagram of the SUPERCLAUS®/caustic scrubber combination is provided in Fig. 1.

SUPERCLAUS®

The SUPERCLAUS® process has been in use in the Industry since 1988, and now has over 140 units in operation throughout the world. The SUPERCLAUS® process consists of a thermal stage followed by three or four catalytic reaction stages with sulphur removed between stages by condensers. The first two or three reactors are filled with standard Claus catalyst while the last reactor is filled with a specially developed selective oxidation catalyst. In the thermal stage, the acid gas is burned with a substoichiometric amount of controlled combustion air so that the tail gas leaving the last Claus reactor typically contains 0.5 to 0.9 vol-% of H_2S.

The selective oxidation of H_2S to elemental sulphur is not limited by an approach to equilibrium. Also the special SUPERCLAUS® catalyst does not catalyse the oxidation of the formed sulphur to SO_2. A certain amount of air is injected into the process gas entering the SUPERCLAUS® stage, and about 88-92% of the H_2S present in the gas is partially oxidised to sulphur. Since the final-stage reaction is not equilibrium limited, an overall sulphur removal efficiency (SRE) of 99.0-99.4% can be achieved with the installation of a SUPERCLAUS® stage downstream of a Claus unit, depending on the acid gas composition and configuration of the unit.

Caustic scrubber

In the caustic scrubber, caustic is injected, through a non-restrictive jet nozzle, counter current to the inlet incinerator flue gas (see Fig. 2). Liquid collides with the down-coming gas to create the "froth zone", a region of extreme turbulence with a high rate of mass transfer. Quench of the gas temperature, SO_2 removal and particulate removal occur in the froth zone. The clean, saturated gas and charged liquid continue through a separation vessel.

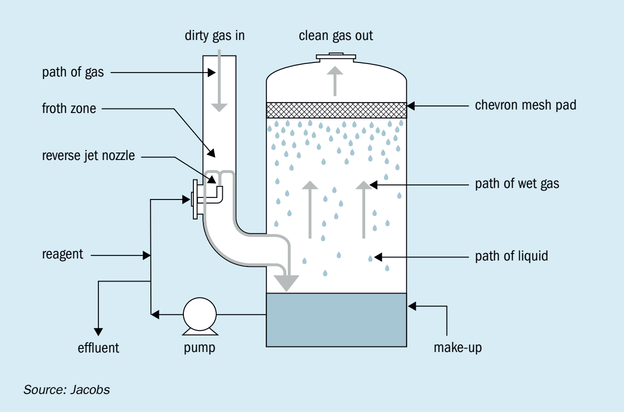
The saturated gas continues through the vessel to mist removal devices, which reduce the losses of caustic to the stack. The liquid, containing caustic reagent, descends into the vessel sump for recycle back to the reverse jet nozzle. In the vessel sump, oxidation air is used to convert sodium sulphite to sodium sulphate. The liquid in the vessel sump is concentrated via a blow down system using a density control sequence.

The installation of a caustic scrubber downstream of an incinerator combines multiple functions in one vessel, providing quench, SO_2, particulate removal and oxidation. Quench occurs during the contact between the incoming gas and the liquid/reagent stream. As such, a separate quench zone is not required. At the same time, reaction between the reagent and the SO_2 takes place, also during contact and intense mixing in the froth zone.

SUPERCLAUS®/caustic scrubber combination

The benefits of combining a SUPERCLAUS® plant with a caustic scrubber are twofold: (1) lower capital and operating costs and (2) very high sulphur recovery removal efficiency. The installation of a SUPERCLAUS® unit, increases the sulphur recovery efficiency of a typical three stage Claus unit from about 97.5% to 99.0-99.2%. Combining this with a caustic scrubber downstream of the incinerator, an overall sulphur removal efficiency of greater than 99.95% (with 50-100 ppmv SO_2 emissions) can easily be achieved with a much lower caustic consumption and disposal compared to a conventional Claus unit. Using SUPERCLAUS® reduces the operating cost by about 85%. Depending on the existing infrastructure for caustic supply and disposal of caustic, the operating costs may also prove to be lower than an amine based TGTU, however this should be evaluated on a case by case basis. The estimated capital cost of a SUPERCLAUS®/caustic scrubber combination is about 35-40% lower than an amine based TGTU of equivalent capacity. This cost comparison can be sensitive to plant size, site conditions, plot space availability, and certain client requirements. However, with all factors considered, it is believed that the capital cost comparison for most applications will show a very significant advantage and lower cost for a SUPERCLAUS®/caustic scrubber combination.

Fig. 2: **Caustic scrubber design**



Source: Jacobs

The SUPERCLAUS®/caustic scrubber combination has several other advantages over an amine based TGTU:

- There is no recycle of acid gas to the front of the SRU, which allows for a higher processing capacity of about 5%.
- The number of equipment items compared to an amine based TGTU is substantially lower and it does not include a quench water or amine system.
- It is much less sensitive to upstream SRU operations and the caustic scrubber is typically designed to handle a SUPERCLAUS® stage bypass scenario. The caustic scrubber can handle SO_2 upset scenarios without potential for fouling or severe corrosion which is a potential with an amine based TGTU.
- It does not require a precise air control for an exact "H_2S/SO_2" tail gas ratio control of 2/1. The SUPERCLAUS® air control is much more forgiving.
- Vent air streams from sulphur degassing systems can also be processed in the caustic scrubber, allowing operation of the degassing system at low pressure.
- It requires much less plot space for major equipment.
- It uses much less energy and thereby has a lower CO_2 footprint.
- It is much simpler to operate and maintain.
- It should have a higher "on-stream" factor for the SRU/TGTU complex.

The waste stream from the caustic scrubber can be further treated to minimise disposal costs and in general the waste stream is a small quantity compared to for instance a caustic based wet gas scrubber for FCC units.

Operating experience

The first SUPERCLAUS® units followed by a caustic scrubber have been in operation since 2014 at a refinery in far-east Asia and have been successful in meeting the required high removal of sulphur. During the most recent performance test of the unit, the SO_2 concentration in the stack gas was below 10 ppmw, indicating that a sulphur removal efficiency of greater than 99.99% was being achieved by the plant.

There are currently an additional five SUPERCLAUS®/caustic scrubber combinations in design or construction, which include the learnings from the first operational installation. ■

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SULPHUR
ISSUE 379
NOVEMBER-DECEMBER 2019
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Subscription rates:
GBP 440; USD 880; EUR 680

Subscription claims:
Claims for non receipt of issues must be made within 3 months of the issue publication date.

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Previous articles from *Sulphur* from 1995 to the present are available digitally in PDF format. To make a purchase, or for a list of available articles, please see: www.bcinsight.com

ISSN: 0039-4890

Design and production:
JOHN CREEK, DANI HART

Mixed Sources

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

BCInsight

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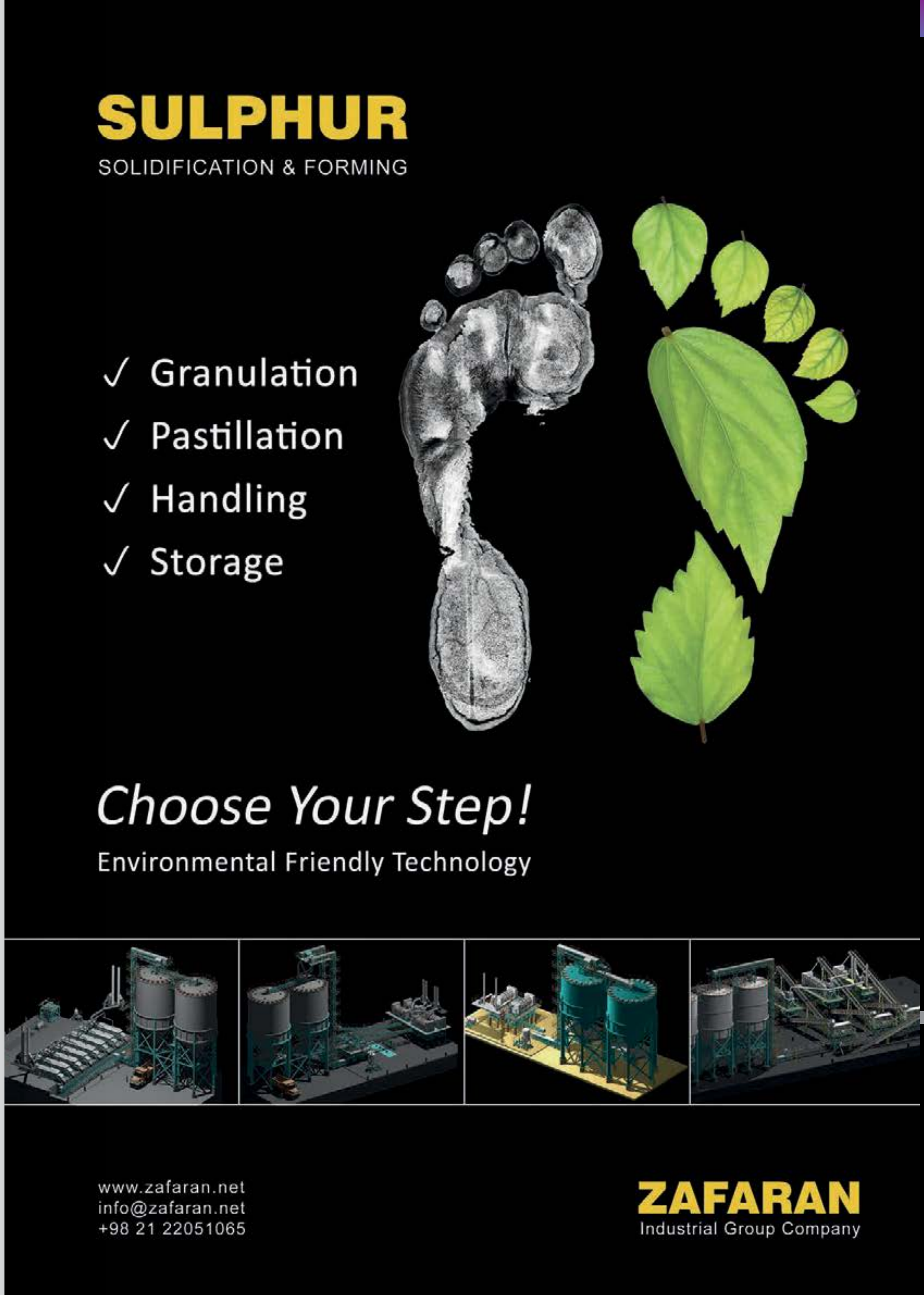

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