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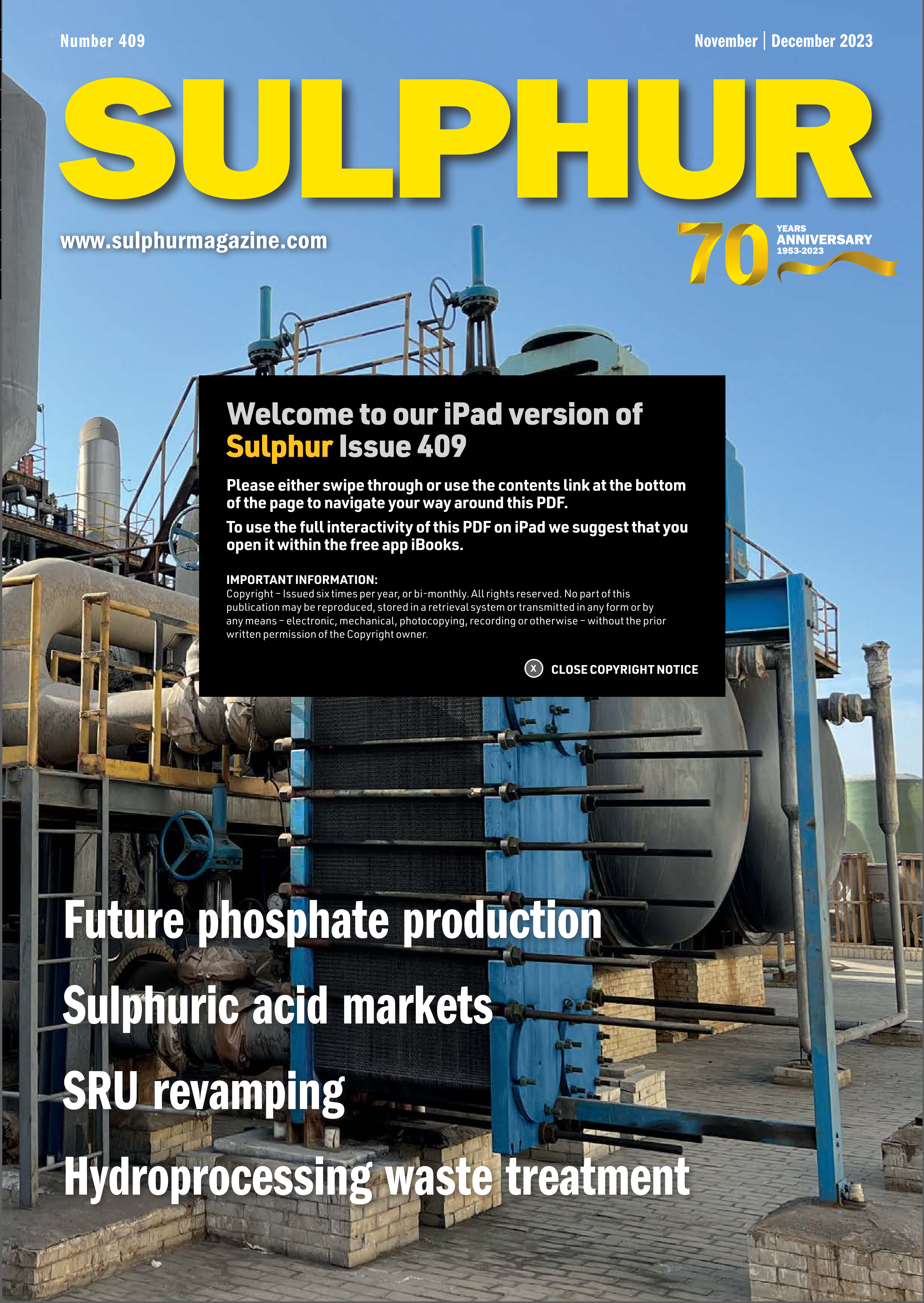

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Future phosphate production

Sulphuric acid markets

SRU revamping

Hydroprocessing waste treatment

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Cover: *Sulphuric acid plant, Baiyin, China. Photo: Alfa laval*

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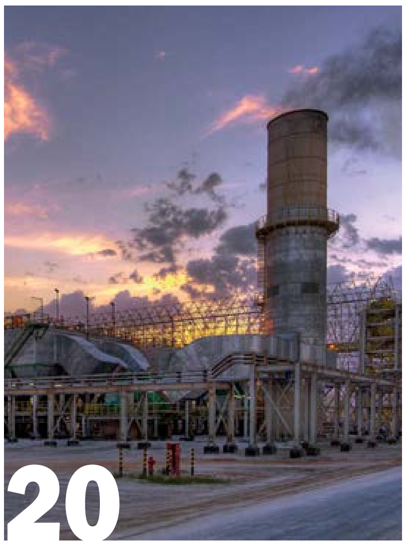

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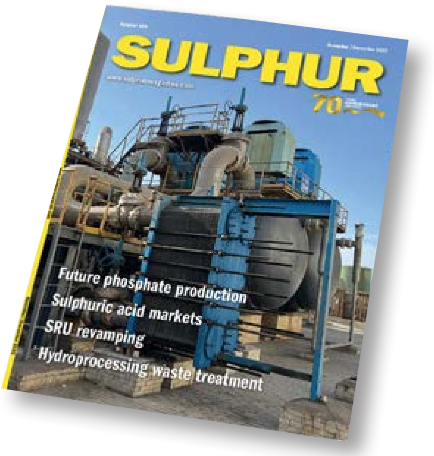
Published by: BCInsight

Editorial

Change is already here



One of the things that produced a lot of worried news headlines over the past couple of years is whether the energy transition is likely to lead to a shortage of sulphur as we switch away from fossil fuels on a large scale. As we've discussed in this magazine, those fears are overblown, certainly in the medium term future. Peter Harrison of CRU tackled the issue in his sulphur markets presentation at the recent Sulphur and Sulphuric Acid conference in New Orleans, and while he did admit to some reduction in sulphur supply from oil in the 2030s and increasing into the 2040s, increased sulphur recovered from sour gas is likely to more than make up for that at least until the 2040s. But one of the things that did strike me about his presentation is the extent to which the energy transition is indeed already changing the way that the sulphur market works, and will increasingly do so over the next few years.

> **"The energy transition is already changing the way that the sulphur market works..."**

The reason for this is battery technology and the metals required for the rapid uptake of electric vehicles. In particular, rapidly increasing global demand for nickel and lithium is driving major project expansions in Indonesia and the US respectively. Indonesian high pressure acid leach nickel projects are coming on stream and beginning to use increasing amounts of imported sulphur, possibly up to 4 million t/a over the next few years. Likewise US lithium leaching projects will need acid and most have dedicated sulphur burning acid plants that will need additional volumes of sulphur. This comes at a time when US refineries are closing or converting to biofuels – another fruit of the energy transition - reducing US domestic sulphur production and leading to increasing imports. Net US sulphur imports could reach 3 million t/a by 2028. As Chinese imports of sulphur decline, we will see more cargoes heading for the US and Indonesia, changing the patterns of world sulphur trade. Indeed, Morocco, Indonesia and the US together represent almost all incremental new import demand for sulphur over the next five years.

Patterns of sulphur supply are changing too, but here not because of the energy transition, but rather because of the construction of new globally-oriented refineries in the Middle East and new sour gas exploitation, especially in the UAE. Abu Dhabi is already the largest sulphur exporter in the world, but this could rise past 11 million t/a over the next few years due to projects like the Shah expansion – one of the reasons that the world is not going to run out of sulphur any time soon!

The sulphur industry has already seen some major shifts in where sulphur is produced and consumed. The decline of sour gas production in North America and its rise in China, Central Asia and the Middle East, and the drift of refining capacity from Europe and North America to Asia has already been a profound change on the supply side, and the rise of phosphate production in China, India, Brazil and Morocco and metal leaching in Chile, Africa and the Philippines have also been major changes on the demand side. But it appears that we are now on the cusp of a change that will be equally momentous, and we are only just seeing the beginning of it.

Richard Hands, Editor

Market Outlook

MARKET INSIGHT

Maria Mosquera, Editor of the Argus Sulphur Report and **Liliana Minton**, Editor of the Argus Sulphuric Acid Report at Argus Media assess price trends and the market outlook for sulphur and sulphuric acid.

SULPHUR

Volatility in sulphur prices has been reduced in the past year following the large price spike and subsequent drop in the summer of 2022. This price volatility has been due to various disrupted seasonal trends from the global pandemic, uneven recovery, geopolitical shifts and demand destruction for fertilizers. Changes to trade flows that have taken place during 2023 have been guided by geopolitical considerations. This again illustrates how the important conversations around sulphur today are not about how much sulphur is globally produced, but affordability and the cost of logistics from the site of production to the site of consumption.

During 2023 US, EU and UK sanctions on Russia have had implications on prices and direction of export flows from Russian ports. Russian-origin product has become somewhat marginalised in terms of price and destination, as many sulphur consumers have self-sanctioned as a result of a greater business risk, banking difficulties and higher costs of transport. Kazakh product exported via Russian ports has also, to a lesser extent, been impacted. This has increased price spreads from the Baltic and Black Sea, as well as depressing f.o.b. netbacks against other suppliers. Some tonnes that load at Georgia's Batumi port can bypass Russian port and vessel restrictions. However, product export flows have not halted.

The key market Chinese sulphur demand is constrained by two significant factors. One is the substantial level of port stocks, reaching around 2.7-2.8 million tonnes in November. This is a significant level of stocks; a two year high since October 2020, when China's sulphur stocks averaged 2.9 million tonnes. The stocks were drawn down over a period of reduced import buying in favour of domestic business. This is also likely to occur at the end of 2023.

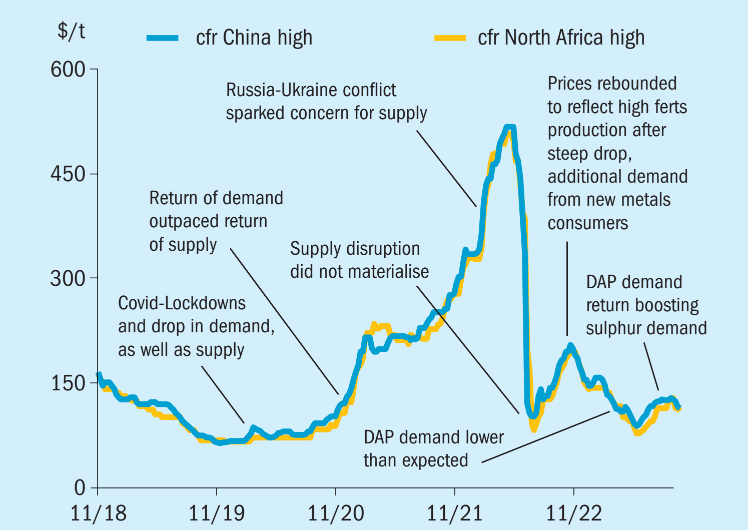
Additionally, China's main economic planning body the NDRC suspended customs inspections for phosphate fertilizers for export on 9th November with immediate effect and until further notice because of a rise in domestic prices. This is expected to lead to a reduction in run rates, and sulphur consumption, among Chinese fertilizer producers. Without an export outlet and the domestic market often providing less of a financial incentive to keep producing at high rates, sulphur demand will likely be curbed while restrictions remain in place.

The lack of any significant flows of sulphur exports via the barge route to Black Sea ports has also disrupted the seasonal price trend, where the closure of the lock system from November to March would lead to a pick-up in prices at the end of the year. No Gazprom sulphur was sent along the Volga-Don river route to Kavkaz this year, as has been the case since 2020-21, when barge exports dropped from an annual 1.5 million t/a to 346,000 t/a and then to nothing in 2022.

However, substantial Middle East flows moving to North Africa during the fourth quarter are reducing available spot tonnes and as such supporting prices from any dramatic erosion. In addition to this, regular spot demand from Indonesian nickel producers has mitigated some of the missing Chinese demand. Chinese c.fr levels have at times trailed delivered prices to what is emerging as a premium market in southeast Asia for Indonesia's growing nickel refining industry.

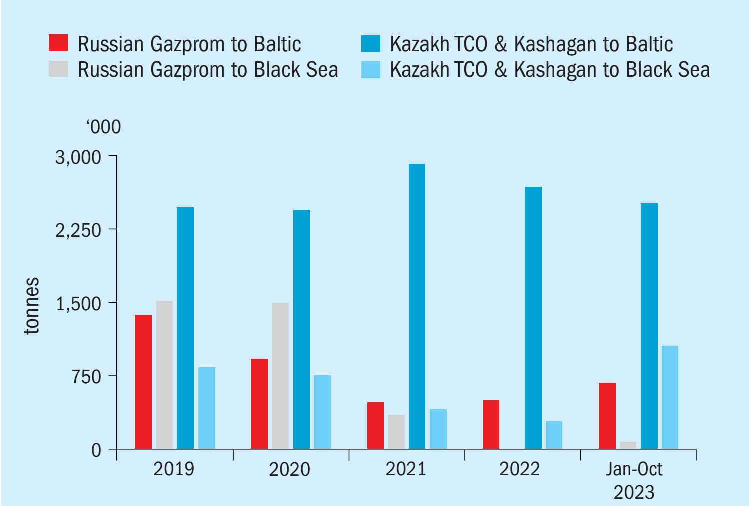
The year 2024 does not appear to be the year when geopolitics becomes less impactful on trade flows. While the likelihood for the kind of volatility that was seen in sulphur pricing last year is judged to be low, there is a risk for higher freight rates and a reconfiguration of trade flows leading to short term disruptions if geopolitical turmoil persists or escalates. Higher delivery costs would cap achievable netbacks for suppliers next year, with downstream demand from the phosphate industry likely to remain somewhat lacklustre moving to 2024, weighing on delivered prices.

Fig. 1: **Key sulphur cfr prices 5-year trend to 10 November 2023**



Source: Argus Sulphur Price Reporting Service

Fig. 2: **Major Russian and Kazakh sulphur producer product railings to seaports**



Source: Russian rail data

Note: Black Sea ports include Kavkaz, Taman, Batumi and Chornomorsk

SULPHURIC ACID

Global sulphuric acid prices have remined firm into the fourth quarter as demand from Moroccan fertilizer buyer OCP returned in mid-August, thus tightening sulphuric acid availability in Europe and Asia.

Northwest European prices peaked this year at $65/t f.o.b. at the end of October, a considerable recovery from the $5.50/t f.o.b. recorded in mid-July, as prices quickly reacted to heavy spot buying from OCP – which entered the spot market to secure approximately 500,000 tonnes of acid of European and Asian origin combined, for delivery in the last four months of the year.

Asian prices also saw sharp increases as Chinese f.o.b. prices peaked at $47.50/t f.o.b. on 21st September, but have since then fallen to $35.50/t f.o.b. on 9th November on a combination of higher domestic availability coupled with the lower demand from the domestic fertilizer sector.

Chinese f.o.b. prices may continue to experience some downward pressure as Chinese smelter-based acid availability is to increase following new capacity coming on line. The start-up of Guangxi's Nanguo smelter – with a capacity of 1.6 million t/a – in September and capacity expansions at Shandong's Dongying Fangyuan copper smelter, Baiyin Nonferrous and Houma north Copper are also expected to increase availability.

But it was not just OCP who returned to the market in August/September, demand from Chile – largest sulphuric acid offtaker – was also active in August-September, and resulted in delivered prices to rise as demand was met with tighter supply from key origins.

Sulphur reclamation at OCP, Jorf Lasfar.

PHOTO: TSK

Chile experienced domestic supply disruptions following an unplanned outage at Noracid's sulphur burner in August and output issues at Enami's Paipote smelter following its return from heavy maintenance also that month, which tilted the domestic market into deficit, and forced buyers to enter the spot market to cover the domestic supply shortage.

Current delivered prices to Chile averaged $150/t c.fr in October, well above the $90/t c.fr when prices bottomed out in July, thus making Asian import tonnage viable considering current Asian fobs and freight rates.

Looking forward, demand from Chile next year is expected to be largely unchanged as the decommissioning of BHP's Cerro Colorado at the end of the year is expected to be partly offset by lower domestic production following the decommissioning of Codelco's Ventanas smelter at the end of May.

End users in Chile are expecting sulphuric acid prices to trend lower in 2024 and as such buyers are keeping a larger proportion of their annual volumes to be fixed on a variable basis – either on formula or on a quarterly pricing negotiation.

Base metal prices have been volatile in October and into November, and heavily influenced by economic sentiment coming out from China and a strong US dollar. Persisting high inflation levels have also weighed on metal prices.

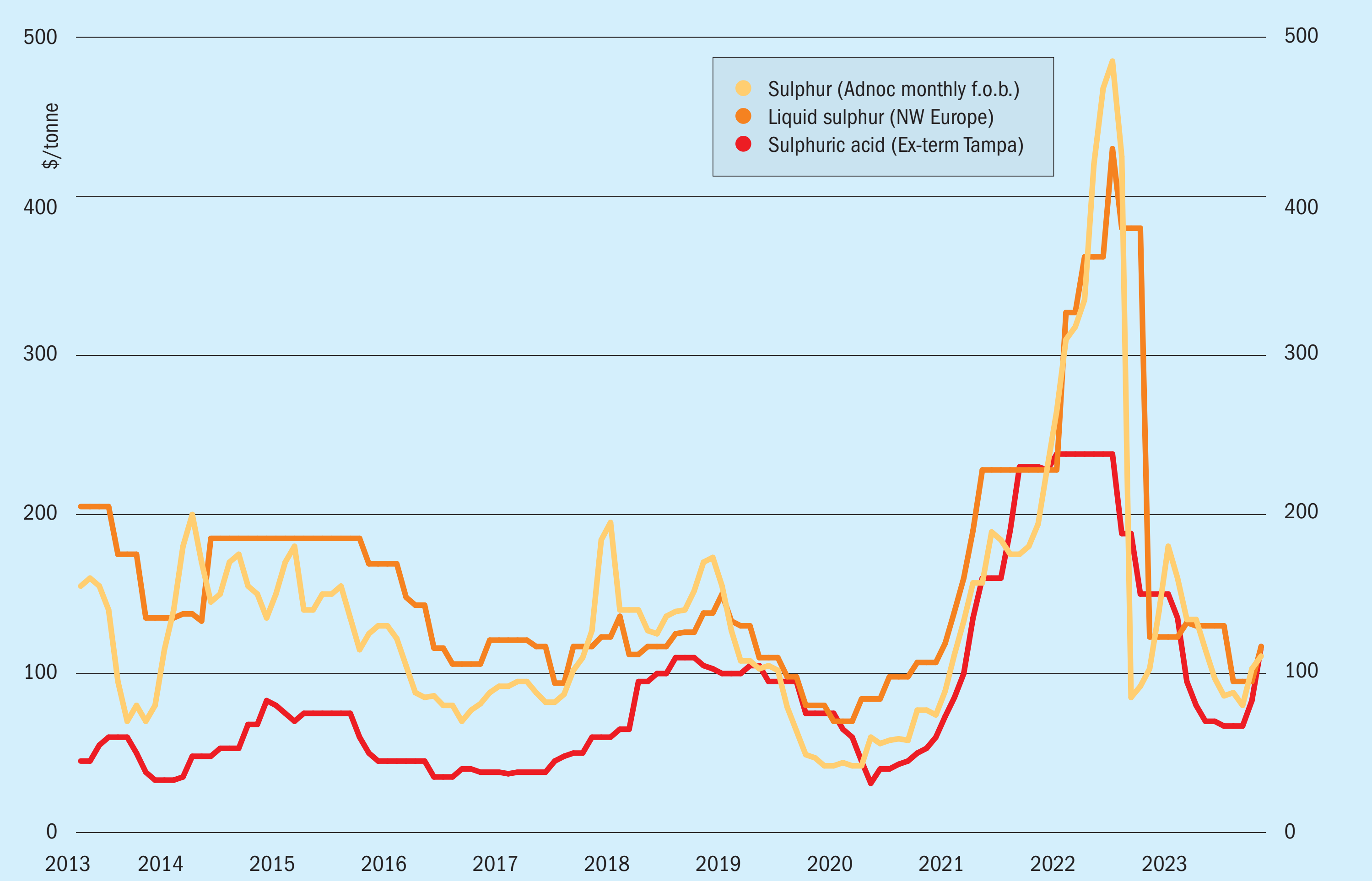
Price Indications

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

Cash equivalent	June	July	August	September	October
Sulphur, bulk ($/t)					
Adnoc monthly contract	86	88	80	103	111
China c.fr spot	112	113	113	120	128
Liquid sulphur ($/t)					
Tampa f.o.b. contract	103	55	55	55	102
NW Europe c.fr	130	95	95	95	117
Sulphuric acid ($/t)					
US Gulf spot	67	67	67	83	117

Source: various

Historical price trends $/tonne



Source: BCInsight

SULPHUR

- A softer trend in DAP prices, linked to lower operating rates in China and declining demand, is contributing to falling sulphur prices.
- However, west of Suez, healthy November bookings for Moroccan and Brazilian markets are expected to provide market support and limit any downside. A softening in freights assessments should also support supplier f.o.b. prices.
- Chinese sulphur import demand is likely to be weighed down in the short term by high port stocks and reduced fertilizer exports as a result of ongoing export controls.
- However, at present sulphur demand for Indonesian high pressure acid leaching nickel production is mitigating some of the shortfall from Chinese imports in Pacific markets.
- North African demand for sulphur is continuing to increase due to OCP's new phosphate production in Morocco.
- Geopolitical considerations such as the conflict in Ukraine have altered global trade flows of sulphur and limited netback prices, and this situation is expected to persist into 2024.
- High freight costs and geopolitical turmoil remain significant risks to trade flows, and hence there may well be short term price volatility were it to be the case that there any bottlenecks in supply arise next year.

SULPHURIC ACID

- Morocco remains in the market for sulphuric acid tonnages for early 2024 arrival. The sulphuric acid line up at Jorf Lasfar was estimated at a total of 330,000 tonnes scheduled for arrival during 4Q23.
- Chilean sulphuric acid demand is expected to remain firm next year, with more end users keeping some of the volumes to be supplied by the spot market in anticipation of lower f.o.b. prices in Asia. The rise in northwest European prices and the ongoing logistics issues in vessels crossing the Panama Canal will likely affect vessel arrivals into Chile and result in more acid remaining in nearby destination markets.
- European suppliers are sold out for October-November loading. Some additional European supply could become available for December loading considering the current high export prices, but it remains to be seen if European producers can manage to free up some tonnes for loading towards the end of the year.
- European acid pricing is expected to remain firm next year as heavy maintenance at key smelters – such as Aurubis' Hamburg smelter – is scheduled in the second quarter of 2024, which will tighten acid availability from Europe.
- Chinese acid pricing is expected to soften as 2024 progresses on the back of new smelter acid capacity coming online, as well as output ramp-ups from already completed projects. However, a risk to the forecast could be a strong domestic market, which may limit acid availability for the export market.

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Sulphur Industry News

UNITED ARAB EMIRATES

Hail and Ghasha contracts awarded

Tecnimont, part of MAIRE's Integrated E&C Solutions business unit, has signed a letter of award with ADNOC for the onshore processing plant of the Hail and Ghasha Development Project. The award was signed at ADIPEC, the world's largest energy summit. The project aims to operate with net zero CO_2 emissions, in part due to the facility's CO_2 carbon capture and recovery units, which will allow the capture and storage of CO_2. The project will capture 1.5 million t/a of CO_2, taking ADNOC's committed carbon capture capacity to almost 4 million t/a. The company recently announced its decision to double its carbon capture capacity to 10 million t/a by 2030. The Hail and Ghasha CO_2 will be captured, transported onshore and stored underground, while low-carbon hydrogen will be produced to replace fuel gas and further reduce emissions, according to ADNOC. The project will also use power from nuclear power plants and renewable sources from the grid.

The overall EPC contract value is approximately $8.7 billion, with first production expected in 2025 and project completion scheduled for 2028, by which time gas capacity will have reached 1.5 bcf/d, alongside 120,000 bbl/d of oil and condensates. The scope of work includes two gas processing units, three sulphur recovery sections, the associated utilities and offsites as well as export pipelines. Tecnimont will also use MAIRE's Sustainable Technology Solutions division to develop innovative digital solutions aimed at reducing emissions and optimizing energy consumption, allowing a significant efficiency of the plant in terms of opex and capex. The engineering and procurement activities will be executed by several dedicated teams in Europe, India and the UAE.

Alessandro Bernini, MAIRE Group CEO, commented: "Today we have been awarded the largest contract ever for the MAIRE Group, a multi-billion-dollar project which will significantly boost the delivery of our 10-year strategic plan. We are honoured to have achieved this great result with a leading global player such as ADNOC, as it represents further evidence of the strength of our long-lasting and fruitful relationship. This award, a landmark recognition of Made in Italy Engineering, is a demonstration not only of our leadership in sulphur recovery and in gas treatment plants but, more broadly, of our undisputed execution capabilities as well as our technological expertise in designing carbon-free industrial solutions."

ADNOC has also awarded an $8.2 billion engineering, procurement and construction contract for the offshore facilities, which includes facilities on artificial islands and subsea pipelines, to a joint venture between the domestic National Petroleum Construction Co. and Saipem SpA. Saipem says that its share of that contract is valued at $4.1 billion and includes four drilling centres and one processing plant to be built on artificial islands, as well as various offshore structures and more than 300 km of subsea pipelines. Saipem said it will use its shallow water offshore vessels and advanced welding technology for corrosion resistant materials for the project.

ADNOC operates the Ghasha concession with 55% interest on behalf of partners Eni with 25% interest, Wintershall Dea with 10%, OMV with 5% and Lukoil with 5%.

There have been concerns about rising project costs, however. A recent report by Wood Mackenzie estimates project costs at $20 billion for Hail ad Ghasha, due to the sour gas and sulphur handling costs, and suggests that ADNOC may ultimately need to spend double that to achieve its growth strategy targets. In late September 2023, ADNOC awarded a $615 million EPC contract to Petrofac for the Habshan carbon capture, utilisation and storage project. ■

WORLD

Oil production cuts lead to price hikes

Saudi Arabia and Russia have agreed to continue coordinated oil production cuts, described by the IEA as a "formidable challenge for oil markets" as the price of Brent crude has climbed well above $90/bbl in response to a tighter market where demand now exceeds supply. The IEA said in its September Oil Market Report that following relative calm during August, with volatility at multi-year lows, the decision by Saudi Arabia and Russia in early September to extend output cuts of a combined 1.3 million bbl/d through year-end triggered a price spike in North Sea crude to a 10-month high. The IEA estimates that the recent extension of coordinated voluntary supply cuts by Saudi Arabia and Russia will result in "locking the world oil markets into substantial deficit."

However, the cuts leave Saudi Arabia producing only 9 million bbl/d, down from 11 million bbl/d a year ago. At present, OPEC+ appears to be maintaining a united front and remain committed to supply restraint. However, high oil prices and OPEC+ production cuts tend to stifle demand growth and boost supply outside of the bloc in the longer term.

The IEA also notes in its report that global refinery runs are set to rise by 1.7 million bbl/d to 82.4 million bbl/d this year. Chinese refinery output surged to 15.5 million bbl/d in August, up by 2.6 million bbl/d on the year and marking a new record. By contrast, OECD Europe's refining activity fell by 370,000 bbl/d year on year to 11.49 million bbl/d, as refinery utilisation rates slumped by 2% on the year to 84%. Germany and Italy recorded utilisation rates below 80%. OECD Americas runs rose by 320,000 bbl/d on the year to 19.5 million bbl/d in August. US refinery activity was supported by the lack of weather-related disturbances and a low number of unplanned outages. Mexican utilisation rates stood at just 50%. Global crude processing rates are still below August 2019 levels of 84.5 million bbl/d, signalling an incomplete post-pandemic recovery in refining activity. Among contributary factors are delays to the start-up of the 650,000 bbl/d Dangote refinery in Nigeria and Mexico's state-owned Pemex 340,000 bbl/d Olmeca refinery. Global refinery margins fell in September from August levels, mostly as a result of a decrease in gasoline and fuel oil crack values. But strong diesel and jet fuel cracks supported global refinery margins above seasonal averages.

CHILE

Refinery reduces FCC sulphur emissions

Chilean oil refiner ENAP Refinerías has started up a newly installed wet gas scrubber at the Aconcagua Refinery at Concón. The scrubber uses Elessent BELCO® technology and is the second wet gas scrubber installed on an ENAP fluid catalytic cracking unit, with the first one commissioned in 2019 at the Bío Bío Refinery. The installation will reduce sulphur oxides and particulate emissions from the FCC to well below Chilean regulatory requirements.

Ramiro Abel Gonzalez, Latin America Business Development Manager, Elessent Clean Technologies, said; "The startup of this project serves to improve emissions control with the highest operational reliability, and it has established ENAP as a leader in protecting the environment. By developing tailored emission control solutions, Elessent is delighted to be able to help refinery customers worldwide meet site-specific environmental, energy consumption, cost and operation targets."

BELCO technology uses a proprietary water spray tower equipped with a filtering module and droplet separators. Larger particulate and SO_2 are removed in the spray tower, and fine particulate is removed in the filtering module section, so that only cleaned flue gas leaves the tower. The process is fully automated, and the new custom-designed system has analysers that allow for constant online monitoring.

CANADA

Chemtrade announces 3Q results

Chemtrade has announced results for the three months ended September 30, 2023. They include an adjusted EBITDA of $142.1 million, up 3.7% year-over-year, with improved margins offsetting lower revenue, which was $483.5 million, down 7.0% year-over-year, due in part to lower prices for the Sulphur and Water Chemicals segment. SWC reported revenue of $290.5 million for 3Q 2023, compared to $311.5 million for the third quarter of 2022 due to lower selling prices for merchant acid and sulphur products due to lower sulphur costs; and lower sales volumes of merchant acid and ultrapure sulphuric acid.

Chemtrade continues to work on two large ultrapure sulphuric acid growth expansion projects in Cairo, Ohio and Casa Grande, Arizona. The project in Cairo continues to progress on schedule and on budget, with construction completion expected in the first quarter of 2024 and commissioning and start-up expected later in 2024 and commercial ramp-up expected in 2025. As regards Arizona, the joint venture analysed the results of the FEED study and has looked for cost savings where possible.

UNITED STATES

KP to partner Agra on sustainable aviation fuel

KP Engineering has been selected as the engineering, procurement, fabrication and construction management partner for Agra Energy's series of sustainable aviation fuel (SAF) plants. These units will produce sustainable aviation fuel or renewable diesel from effluent waste from dairy farms.

"We are honoured to be a trusted partner for another project that converts waste to value, and to be working alongside a revolutionary developer like Agra," said William E. Preston, CEO, KPE. "Their technology will fundamentally improve the operational sustainability of dairy farmers in America and abroad."

Tony Long, CEO, Agra Energy, comments, "Working with KP Engineering has been instrumental in our operational know-how, start up and commissioning. Now that the first unit is producing, we look forward to partnering with KPE to further optimize for the second, third and many units to come as we scale. This will offer benefits to farms and communities in building a better world."

KPE's scope of work consists of commissioning and startup assistance on Agra's first plant, incorporating lessons learned into the design for succeeding units, incorporating SAF production capability into that design, updating the total installed cost estimate and executing the full EPFC on the second plant. When completed and operational, the second plant will produce between 40-60 bbl/d of renewable fuel. The second plant is scheduled to begin operations in the fourth quarter of 2024.

Analysis of impurities in hydrocarbon gas streams

AMETEK Process Instruments has introduced a new analyser capable of simultaneously measuring multiple sulphur compounds, hydrogen and carbon dioxide in one unit – the 9933. The wall or panel mountable analyser is designed for outdoor or indoor installations, with standard ingress protection ratings of IP66 and NEMA 4X, and proven operation in ambient temperatures ranging from -20°C to +50°C. The 9933 is certified for use in ATEX/IECEx/UKEx Zone 2 and North America Class I Division 2 hazardous areas, with a Zone 1 configuration pending.

Like its predecessor the Model 933, the 9933 uses ultraviolet spectroscopy to measure hydrogen sulphide, carbonyl sulphide and methyl mercaptan levels. Unlike the Model 933 however, the 9933 can incorporate optional gas sensors that measure CO_2 and H_2 concentrations, addressing new measurement requirements being implemented to decarbonise energy.

With decades of experience measuring sulphur components in sales gas, gas processing and refinery process streams, AMETEK focused on developing the 9933 with features requested from Model 933 end users and maintenance teams. Standard features include a 7″ colour touch screen display, Modbus TCP and Modbus RTU support, at least four isolated and self-powered analogue outputs, and longer lamp life. Like the Model 933, long service life elution columns are utilized and continuously regenerated, so there is no need to frequently monitor and replace scrubber media for 0-3ppm measurements.

IRAQ

Iraq to invite bids for sour gas development project

Iraq intends to invite global firms to submit bids for the development of a southern onshore oilfield as part of a drive to tap its massive gas resources. The bids are for the development of the Nahr bin Umar field near the southern city of Basra, operated by the state-run South Gas Company. The aim is to produce around 150 million cfd of sweet gas and an equivalent amount of sour gas from Nahr bin Umar, possibly also including gas liquids and condensates, with the project to be awarded on BOOT (build-own-operate-transfer) basis.

KAZAKHASTAN

Funding for Kashagan gas plant

Kazakh state run holding Samruk-Kazyna has signed an agreement with the Bank of China to arrange a loan to fund building a gas processing plant that will handle additional associated output from the Kashagan field in Kazakhstan's sector of the Caspian Sea. An additional 1 bcm of associated sour gas will be processed by the new onshore plant, allowing Kashagan to boost production by about 25,000 bbl/d.

PHOTO: TRAFIGURA

The Bahia Blanca refinery, Argentina

ARGENTINA

Trafigura to instal diesel hydrotreater

Elessent Clean Technologies has signed license and engineering contracts with Trafigura for the construction of a 125 m^3/h (18,870 bbl/d) IsoTherming® diesel hydrotreater at the Bahía Blanca refinery in Argentina. The refinery currently operates on domestic crude sourced from the Vaca Muerta and other regions of Argentina. The project represents a major investment by Trafigura in expanding the refinery's diesel capacity and enhancing its ability to produce and sell ultra-low sulphur diesel (ULSD) domestically. This move will also position the refinery to meet the upcoming regulation that requires a reduction in the maximum sulphur content in ULSD to 10ppm. Start-up for the unit is expected in 2025-26

IsoTherming improves the quality of diesel fuel by removing sulphur, nitrogen, and other impurities, and also has lower carbon emissions than a traditional hydroprocessing unit. Through the use of a liquid-full reaction zone and an effluent recycle loop, it requires less heating from the feed charge heater, resulting in less fuel gas burned. Additionally, the diesel hydrotreater unit will be designed to optionally co-process renewable feedstock in the form of vegetable oil, giving the refinery the latitude to replace a portion of its feed with a non-fossil fuel source while producing a high-quality diesel product.

"It has been a pleasure to work with Trafigura over the course of this project, and we're grateful for the opportunity to build this working relationship. The unit at the Bahía Blanca refinery will reduce energy consumption and CO_2 emissions by approximately 50% in comparison to traditional hydrotreating technology," said Samantha Presley, Global Business Leader – New Capacity for Refining Technologies at Elessent.

SAUDI ARABIA

Hyundai wins gas plant expansion project

Hyundai Engineering has secured a major project in Saudi Arabia worth $2.3 billion for the expansion of a major gas plant. The signing occurred at the NEOM Exhibition Hall in Riyadh between Hyundai Engineering and Saudi state-run oil company, Aramco, for the Jafurah 2 Gas Plant Package. The project will be adjacent to the site of the Saudi Jafurah Gas Treatment Facility Project (Phase-1) that Hyundai Engineering and Hyundai E&C undertook in 2021. It encompasses facilities that process gas produced from the Jafurah gas field and additional infrastructure for sulphur recovery.

A representative from Hyundai Engineering stated, "Securing the Jafurah expansion project is a testament to our world-class technical prowess and outstanding Engineering, Procurement, and Construction (EPC) capabilities. We are committed to successfully executing this project and establishing a robust position for future orders."

IRAN

South Pars celebrates 25th anniversary

The managing director of Iran's South Pars Gas Company (SPGC) said that 1.96 trillion cubic meters (tcm) of natural gas have been processed by the complex's refineries and injected into the country's gas network since the complex was launched 25 years ago. Speaking to state media, Ahmad Bahoush said: "SPGC was established on 20 October 1998 as one of the subsidiary companies of National Iranian Gas Company (NIGC) which is responsible for the operation of onshore facilities of the South Pars gas field."

He said the first official production and processing of natural gas from the second refinery of South Pars (phases 2 and 3) began in the Iranian calendar year 1380 (2001), adding: "At that time, 50 million cubic meters of feed was received from the platforms of the South Pars gas field and 40 million cubic meters of natural gas was processed on a daily basis."

According to Bahoush, at the time, 80,000 barrels of gas condensate and 400 tons of sulphur were also produced daily. He added: "The feed received by the complex from the platforms of this joint field is now 650 million cubic meters per day, of which 580 million cubic meters of natural gas is produced and transferred to the national network."

South Pars gas field, which Iran shares with Qatar in the Persian Gulf, is estimated to contain about eight percent of the world's gas reserves, and approximately 18 billion barrels of condensate. The field's development is divided into 24 standard phases. In late August, President Ebrahim Raisi officially inaugurated Phase 11 of the South Pars gas field, the last phase of the giant field's development project in the Persian Gulf. Phase 11 will initially produce 15 million cubic meters of gas per day before raising recovery to 56 million cubic meters of gas, 50,000 barrels of gas condensate, and 750 metric tonnes of sulphur per day. The gas from South Pars Phase 11 will be transferred to the onshore refinery of Phase 12, where it will be processed and injected into the national gas network.

MONGOLIA

Contract signed for new refinery

Indian engineering firm Megha Engineering and Infrastructures Limited (MEIL) has received a letter of agreement (LOA) for constructing a new oil refinery from the state-owned Mongol Refinery LLC. The project is valued at $648 million. As part of the engineering, procurement, and construction contract, MEIL will build; a diesel hydrotreater unit, hydrocracker, visbreaker unit, hydrogen generation unit, sulphur block, LPG treating unit, and hydrogen compression and distribution, as well as plant buildings, satellite rack rooms and sub-stations. In addition, MEIL will also build utility and offsite facilities and other enabling facilities. Upon completion, the refinery is expected to process 1.5 million t/a of crude oil annually, meeting Mongolia's domestic demand for gasoline, diesel, aviation fuel, and LPG.

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Sulphuric Acid News

ZAMBIA

FQM to convert acid plant to smelter off-gas

First Quantum Minerals Ltd. has contracted with MECS, Inc. (MECS), a subsidiary of Elessent Clean Technologies, for the Kansanshi smelter expansion at the Kansanshi mine at Solwezi. MECS' scope of work will include a redesign of the existing sulphur-burning sulphuric acid plant into a copper smelter off-gas recovery sulphuric acid plant. This transition to a copper smelter off-gas recovery acid plant will enable First Quantum to reduce emissions from the existing copper smelter, increase production at the mine, and supply more copper to the global market, which will enable the adoption of greener technologies. MECS' design for First Quantum incorporates proprietary technologies such as MECS® catalyst for low emissions and high conversion, Brink® mist eliminators, ZeCor® alloy towers and pump tank and UniFlo® acid distributor technology for operational reliability and efficiency.

"Supporting the Kansanshi smelter expansion with First Quantum and the Kansanshi mine has been an exciting opportunity. Not only is MECS helping to extend the life of the mine and optimize operations, but we are also in a unique position to help make a tremendously positive impact on the environment by helping reduce emissions," said Eli Ben-Shoshan, CEO, Elessent. Startup of the smelter expansion is expected to take place in 2025.

Copper/cobalt slag project

South African metals processing business Jubilee Metals Group has been awarded a copper slag project that will be executed in joint venture collaboration Mopani Copper Mines of Zambia. The Mufulira slag project will process 13 million tonnes of historical slag, estimated to contain 0.7% copper and 0.27% cobalt, in addition to current slag production. Jubilee will design, implement and operate the new processing facility and having the first right to fund the implementation of the project in collaboration with Mopani. Mufulira is a copper belt town located about 40 km from Kitwe. Its copper deposits have been mined over many years, with Mopani owning the Mufulira smelter, where concentrates are blended with toll concentrates to produce copper anodes containing 99.6% copper.

Zambia aims to lift copper output to 3 million t/a, and the slag project is seen as forming part of a greater waste recovery initiative in Zambia to help achieve that mission. Jubilee expects to implement the project in two phases, prioritising the quick-to-process initial slag material, while over the coming six-month period simultaneously completing a process review of the more complex slags. As part of an environmental protection commitment, the upgraded Mufulira smelter is equipped with two acid plants that convert up to 95% of the sulphur dioxide emitted into sulphuric acid.

GERMANY

Aurubis and Metso working on decarbonisation of copper smelter

Aurubis AG says that it will invest in hydrogen-ready anode furnaces at their Hamburg copper processing plant. The company will use complete hydrogen-ready Outotec Anode Furnaces with hoods and auxiliary equipment, designed by Metso, for the anode refining process. Close collaboration with Aurubis was key in designing the hydrogen-ready furnace by Metso, a first in the copper industry. Design input was based on full-scale hydrogen testing done at the Aurubis plant in 2021. The order, the value of which is not disclosed, was booked in Metals' first-half 2023 orders received.

Aurubis expects the new technology in copper production to provide potential savings of 5,000 tonnes of CO2 per year. The Hamburg plant will be one of the first copper smelters in the world to use hydrogen instead of natural gas for the reduction process in its anode furnaces.

INDIA

Coromandel acid plant commissioned

Coromandel International has commissioned a sulphuric acid plant at its fertiliser complex in Visakhapatnam, Andhra Pradesh. The new plant is part of a strategy of backward integration of capabilities to drive greater self-sufficiency in operations, and is the third at the complex in the port city. It has a capacity of 1,650 t/d and has been developed at an investment cost of and set up with an investment of $48 million, and brings Coromandel's sulphuric acid capacity to 1.1 million t/a from its previous 600,000 t/a. The new sulphuric acid plant has been commissioned in a record time of 18 months, and is designed to meet the lowest emission standards globally. The steam generated from the facility will be used for captive power generation. A seawater desalination plant has also been set up to meet additional water requirements. Coromandel said it has partnered with Veolia Water Technology and Solutions for the desalination facility.

India is the third largest importer of sulphuric acid globally, importing nearly 2.0 million t/a. With the commissioning of the new plant, the country's import dependence will go down by 25-30%, Coromandel said, reiterating that it will continue to improve its raw material self-sufficiency and augment fertiliser availability for the farming community. The company has a production capacity of 3.5 million tonnes per annum of complex fertilisers.

Greenfield copper facility to start operations from March

The Adani Group's $1.1 billion greenfield copper facility in Gujarat's Mundra will start operations in March 2024 and mark the group's entry into the industry, according to a recent company statement. Kutch Copper is a greenfield refinery project with an annual capacity of 1.0 million tonnes. The project, which will be completed in two phases, aims to produce copper cathodes and rods, along with byproducts like gold, silver, nickel, and selenium. The integrated complex will also produce sulphuric acid for fertilisers, detergents, pharmaceuticals, paper and sugar bleaching, water treatment, and other industries, the company said.

Kutch Copper will source raw material from Latin America to help ensure an effective national supply chain for India's anticipated future supplies of copper. It will also reduce dependency on the only domestic source for copper, Hindalco, and can potentially meet up to half of demand. Many major acid consumers in the country are based along the Gujarat coast, and they are also set to benefit from the copper unit, the company said.

PORTUGAL

New copper and zinc concentrator

Almina Minas do Alentejo is proceeding with preparations to upgrade its copper and zinc concentrator at the Almina mine in Aljustrel, in the Iberian pyrite belt. The company placed an order with Metso as the key equipment supplier for this project in the first quarter of 2023. Metso has now completed the basic engineering of the grinding island. Delivery of the concentrator plant equipment will take place around the end of the second quarter in 2024, with the project expected to be commissioning by the end of the first quarter of 2025.

"Collaboration between Almina Minas do Alentejo S.A and Metso is strong. We are excited to continue working with Almina on this project, for which they selected us to supply the grinding island, ultra-fine grinding technology, as well as flotation, filtration, and thickening equipment, as well as all slurry pumps. The deliveries will be fast as the plant will be built already within the next 24 months," explains Saso Kitanoski, President for Metso's Europe Market Area.

UNITED STATES

Acid catalyst price hike

Elessent Clean Technologies has announced a global price increase of $1.40/litre for its caesium-promoted MECS® sulfuric acid catalyst products and $0.40/litre for all other sulfuric acid catalyst products. Additional charges may apply for freight, near-term delivery and specialty product grades. Subject to the terms of applicable contracts, the new pricing will take effect immediately.

KAZAKHSTAN

New copper concentrator for Kazakhstan

Metso has signed a contract for the delivery of a new copper concentrator to be built in Kazakhstan at a cost of approximately euro 85 million. Metso's scope of delivery consists of the main process equipment for grinding, flotation and dewatering and includes HIGmill® high-intensity grinding mills, TankCell® flotation cells in different sizes in the 30-630 m3, Larox® PF pressure filters, high-rate thickeners, an on-line sampling and analysing system, as well as field instrumentation and Proscon® automation for the whole concentrator plant. The flotation cells, pressure filters and high-rate thickeners are part of the company's Planet Positive portfolio, due to their superior energy and water efficiency.

INDONESIA

Nickel Industries to proceed with HPAL plant

Nickel Industries has taken a final investment decision for its Excelsior nickel cobalt high-pressure acid leach (HPAL) project in the Morowali industrial park in central Sulawesi. The project, known as the Dawn HPAL+ project, is expected to produce 72,000 t/a of contained nickel equivalent in the form of mixed hydroxide precipitate, nickel sulphate and nickel cathode that are all class 1 nickel products. Production is expected to start during October-December 2025, according to Nickel Industries.

The firm has been carrying out a feasibility study for the project, which may lead to a stage two expansion. The expansion, if realised, will double expected production to 144,000 t/a of contained nickel equivalent. The project has also obtained a 15-year tax holiday with two more years of 50% corporate tax cuts from the Indonesian government, said the firm. The firm engaged a "global investment bank" to help with securing offtake and possible project level investment partners, it said, claiming the response has been "very strong". The firm's largest shareholder Chinese investment firm Shanghai Decent Investment will through its affiliate Decent Resource provide a comprehensive construction guarantee that includes covering the project's capital expenditure, so long the total construction costs do not exceed $2.3 billion. Nickel Industries secured $400 million of financing facilities with Bank Negara Indonesia to help fund the project, including a five-year senior term loan facility of $350 million.

Nickel Industries will slowly work its way to owning 55% of the project in phases, with Shanghai Decent eventually owning 25%, and Indonesian construction company United Tractors the remaining 20%. The company also recently signed an agreement with local solar firm Sumber Energi Surya Nusantara to develop a 200 MW solar project in Morowali industrial park to supply electricity to its existing operations and the planned Dawn HPAL+ project in order to reduce carbon emissions.

The nickel market is currently in surplus due to increases in supply from Indonesian projects, but this is expected to be short-lived, with a shortage expected from 2026 onwards as demand for EV batteries picks up. An extra 1.5 million t/a of new nickel demand is expected by 2040. Indonesia now represents 45% of the global nickel market.

PAPUA NEW GUINEA

Ramu back to full production following earthquake

Nickel 28 Capital Corp. says that it has successfully resumed full production levels at the Ramu mine's Basumuk HPAL plant following the earthquake on October 7th. The earthquake, which had a magnitude of 6.7, triggered immediate safety protocols and a comprehensive evaluation of the site's infrastructure. While the event disrupted operations temporarily, the Company says that there were

PHOTO: NICKEL 28

The Basamuk nickel processing plant, part of the Ramu nickel complex.

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no injuries or significant environmental impacts associated with the earthquake or subsequent response efforts. The company is not anticipating any material impact on production and is still guiding for annual production levels at Ramu of approximately 33,000 t/a of contained nickel and 2,900 t/a of contained cobalt in calendar 2023.

AUSTRALIA

Codelco to buy Lithium Power

Chile's state-owned copper producer Codelco plans to buy out Lithium Power International (LPI), with LPI's major shareholder Chilean firm Minera Salar Blanco throwing its support behind the deal. Codelco and LPI have entered into a binding scheme implementation deed, where Codelco acquires LPI through a scheme of arrangement at A$0.57/share ($0.36/share) in cash for a total of A$385 million. The acquisition is a logical consolidation in the Maricunga salt flat and will help position Codelco to strongly "execute our strategy of becoming a globally relevant supplier of critical metals to enable the energy transition", said Codelco's chairman Maximo Pacheco. LPI in 2022 confirmed the potential for its lithium project in Maricunga salt flat to produce 15,200 t/a of lithium carbonate equivalent over a period of 20 years in its first stage.

AUSTRALIA

Alliance Nickel delays definitive feasibility study

Alliance Nickel, developing the $1.2 billion NiWest nickel-cobalt project in Western Australia, says that it will delay a definitive feasibility study until the middle of next year as it grapples with rising cost estimates. In a filing to the Australian Stock Exchange, the company said that it needed time to complete cost optimisation studies and water drilling programs, and would instead publish an updated mineral resource estimate this quarter, with the data to be used to update ore reserve tonnages to be incorporated into the study.

The NiWest project is focused on the proposed Mt Kilkenny mine south-east of Leonora, south of Glencore's Murrin Murrin nickel-cobalt operations, and is one of the largest and highest-grade undeveloped nickel laterite resources in Australia. An updated pre-feasibility study last year gave NiWest a total projected production across 27 years of 456,000 tonnes of nickel sulphate and 31,440 t of cobalt sulphate for supply to electric vehicle battery manufacturers and automakers.

Conico to include HPAL plant

Conico says that it is close to completion of a scoping study for its Mt Thirsty nickel project near the Western Australian town of Norseman. The study will now incorporate the adoption of high-pressure acid leaching (HPAL) and the addition of a plant to produce a precursor cathode active material. Conico is assessing its options against other comparable HPAL projects, which typically attain respective cobalt and nickel recoveries of 90% and 92% respectively.

Glencore to close Mt Isa

Glencore has announced the closure of the three copper mines it owns at Mt Isa as well as the copper concentrator, by the second half of 2025. About 1200 jobs may be lost at what is one of the largest copper mines in the world, with operations dating back to 1924. "Glencore has conducted a range of studies and reviews seeking to further extend the life of the underground copper mines but unfortunately it has not been possible and they have reached the end of mine life," the company said in a press statement in October. "The studies revealed the remaining mineral resources are not economically viable due to low ore grades and areas where, due to geological conditions, safe extraction can't be achieved using current technology, this all coupled with ageing infrastructure."

CHILE

Cochilco says costs are rising

The costs of large-scale copper mining in Chile are rising due to lower production and rising service costs, according to a new report from the state-run Chilean Copper Commission (Cochilco). The report says that the direct cost of copper production reached $1.99/lb in 1H 2023, a year-on-year increase of $0.396. Lower production and the increase in the costs of third-party services, remunerations and prices of materials, electricity and TC-RC (treatment and refining) charges explain the increase in costs, though the report noted a few factors had counteracted cost increases, including higher credits for the sale of molybdenum and gold, and decreases in the cost of sulphuric acid, freight charges and diesel fuel.

DEMOCRATIC REPUBLIC OF CONGO

Zijin to develop Manono lithium project

Chinese multinational mining firm Zijin Mining is to explore and develop the northeast part of the Manono lithium project in the Democratic Republic of Congo (DRC). The mine is one of the largest open-pit exploitable lithium-rich lithium, cesium, tantalum pegmatite deposits in the world, Zijin says. The project is still in an early stage, with construction projected to be completed within two years after the feasibility study and financing plan is determined. A lithium smelting industry park will be built at the same time, with more details including the capacity and launch dates still undisclosed.

Zijin aims to increase its lithium capacity to 120,000-150,000 t/a of lithium carbonate equivalent (LCE) by 2025. It has invested in the Tres Quebradas lithium brine project in Argentina, the Huadao lithium project in central China's Hunan province and the Laguocuo salt lake brine project in northwest China's Tibet region. It has control over 12.15 million tonnes LCE of resources.

RUSSIA

Nornickel launches SO_2 abatement project

Norilsk Nickel has launched the first stage of its sulphur dioxide abatement programme at the Nadezhda Metallurgical Plant. The aim is to radically reduce sulphur dioxide emissions in Norilsk over the next two years. Construction of the abatement plant has taken three years, with equipment delivered by sea for the reconfiguration of metallurgical production at a cost of just under $2 billion. Work has been slowed by sanctions, but Nornickel says that it has found alternative manufacturers and suppliers for the work.

Sulphur dioxide emissions from metallurgical plants in Norilsk have totalled 1.8 million t/a, making it the largest manmade source of SO_2 on the planet. The project being implemented at Nadezhda is based on capture of sulphur dioxide and conversion first into sulphuric acid, and then downstream neutralisation with limestone to produce gypsum. A specialised gypsum storage facility has been created to receive the waste gypsum. The project is being implemented in stages. In the first stage, SO_2 emissions at Norilsk will drop by 20% in 2024 and 45% in 2025 compared to a base year of 2015.

People

Arianne Phosphate says that **Mark Edinger** will be joining the company as an advisor. Edinger is a 15-year veteran of Nutrien Ltd. and its predecessor (Potash Corporation of Saskatchewan) having most recently served as Director of Phosphate Commercial and Product Management Teams, with responsibility for the global marketing of Nutrien's phosphate product lines.

"Over the years, I have watched Arianne advance its Lac à Paul deposit from a grass roots exploration asset to, what is today, one of the most significant phosphate deposits in the world," said Edinger. "Aside from its size and geopolitically safe jurisdiction, Arianne will produce a very high-purity, low-contaminant phosphate that will be required to meet the world's growing demand. Further, as Arianne has already demonstrated, their phosphate is ideal for the materials required for the LFP battery, a market that will significantly increase the importance of the Arianne deposit. I am very excited to be part of this project and use my knowledge and contacts to see it come to fruition."

"I worked closely with Mark for many years at Nutrien and look forward to repeating our success at Arianne," said Raef Sully, former CEO of Nutrien's Phosphate and Nitrogen divisions and member of the Arianne Board of Directors. "Aside from their significant phosphate fertilizer operations, Nutrien also produces purified phosphoric acid, the material required for industrial applications as well as the LFP battery. Mark and I both know first-hand the opportunities for high-purity market and believe that Arianne can be the major player in this market; we look forward to advancing it."

The CEO of Algeria's state oil company Sonatrach **Toufik Hakkar** has been dismissed by Algerian president Abdelmadjid Tebboune, according to state media. His replacement as CEO is **Rachid Hachichi**, the latest in more than a dozen changes of leadership at the strategic firm in 25 years. Hakkar took over in February 2020, replacing Kamel-Eddine Chikhi who was fired after serving less than three months at the helm. Hachichi, an engineer with a long career at the company, had previously led Sonatrach from April to November 2019, replacing Abdelmoumen Ould Kaddour shortly after longtime Algerian president Abdelaziz Bouteflika was forced to step down in the face of mass protests.

Sonatrach is owned entirely by the government, which relies on the company's profits for about 60% of its budget and 95% of export revenues. In recent years it has been shaken by a series of corruption allegations and financial scandals, some of which have prompted investigations in Algeria and abroad. In November 2022 former CEO Ould Kaddour was sentenced to 15 years in prison for corruption over Sonatrach's purchase of a refinery in Italy.

Chilean state copper giant Codelco has appointed **Rubén Alvarado** as the company's new Chief Executive Officer from September 1st. The former general manager of Santiago's Metro has a long career linked to Codelco, where he was general manager of the El Teniente site between 2000 and 2004. He replaces **André Sougarret Larroquet**. In a long and varied career, Alvorado, a civil engineering graduate, was general manager of Metro between 2014-22, corporate general manager of Alsace & Express between 2012-13, director of Engineering and Maintenance of LAN Airlines between 2007-12, project manager for the Techint joint venture between 2005-07 in Argentina and general manager of the San Antonio Port Company between 2004-05. He was also a smelter engineer with Codelco from 1984-93, after which he was promoted to Chief of Research and Technology Transfer and later general manager of the site. In this role he reorganised Caletones Smelter to migrate it from a productive functional orientation to one of business processes, and implemented career development projects for workers. He is the third CEO of Codelco in just over a year. The company has struggled in recent years with falling ore grades, reduced copper output and rising debt from an ambitious $40 billion expansion plan. Shortly after taking charge in September 2023, Alvorado reorganised Codelco's three operational divisions under one roof to be led by **Mauricio Barraza**, the current central-south head. He also intends to merge mining resources and development with innovation and technology in a team run by northern operations VP Nicolas Rivera. Alejandro Rivera has also stepped down as the firm's chief financial officer and Nicole Porcile has resigned as head of sustainability.

Calendar 2023/2024

NOVEMBER

13-16

European Refining Technology Conference, LAGO MAGGIORE, Italy
Contact: World Refining Association
Tel: +44 (0) 7384 8056
Web: worldrefiningassociation.com/event-events/ertc

16

European Sulphuric Acid Association General Assembly, MALAGA, Spain
Contact: Francesca Ortolan, European Sulphuric Acid Association Sector Group Manager
Tel: +32 499 21 12 14
Email: for@cefic.be
Web: www.sulphuric-acid.eu

JANUARY

31-FEBRUARY 2

SulGas Conference 2024, MUMBAI, India
Contact: Conference Communications Office, Three Ten Initiative Technologies LLP
Tel: +91 73308 75310
Email: admin@sulgasconference.com

FEBRUARY

26-28

CRU Phosphates 2024 Conference, WARSAW, Poland
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com

26-29

Laurance Reid Annual Gas Conditioning Conference. NORMAN, Oklahoma, USA
Contact: Lily Martinez, Program Director
Tel: +1 405 325 4414
Email: lmartinez@ou.edu

APRIL

2-4

TSI Sulphur World Symposium 2023, CHALESTON, South Carolina, USA
Contact: Sarah Amirie, The Sulphur Institute
Tel: +1 202 296 2971
Email: SAmirie@sulphurinstitute.org

22-25

Sulphuric Acid Round Table, ORLANDO, Florida
Contact: Cathy Hawyard, Sulfuric Acid Today
Tel: +1 (985) 807-3868.
Email: kathy@h2so4today.com

29-MAY 3

REFCOMM 2024, GALVESTON, Texas, USA
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com

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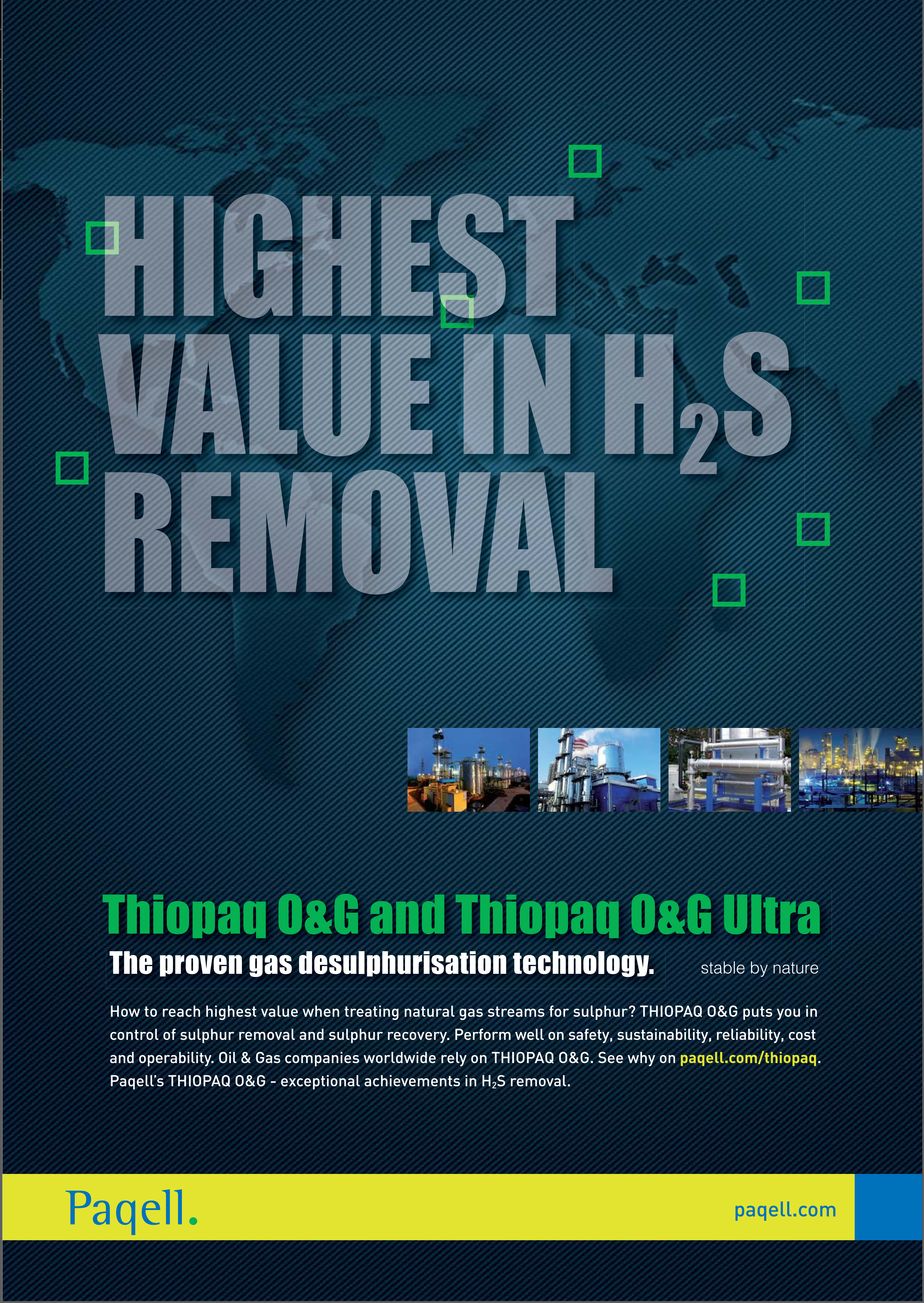

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The future of phosphate production

In spite of changing patterns of demand, deglobalisation and environmental concerns, phosphate mining and acid-based processing are likely to be the mainstay of the industry for years to come.

PHOTO: MA'ADEN

The Ma'aden phosphate plant at Al Jalamid, Saudi Arabia

The phosphate industry has come under scrutiny on various fronts over the years, from its environmental impact, to concerns over resource depletion and even the concentration of its production in the hands of a few, often state-owned companies. But in spite of all of these pressure on the industry, the cost base of acid-leached phosphate for use as a fertilizer is likely to remain the dominant force in phosphate production.

New demand

Around 80-85% of phosphate is used for fertilizer production, either as mono- or di-ammonium phosphate, or single or triple superphosphate. Animal feed additives represent another 7-8%, and the remaining 7-10% is taken up industrial uses for phosphate, including human food additives, toothpaste, detergents, water treatment, metal production, etc. However, a new and promising area of demand for phosphates is coming from the battery industry in the form of lithium iron (Fe) phosphate or LFP. LFP production has increased dramatically in China, mainly for use in car batteries for electric vehicles. As we discussed in our article in the previous issue, current annual growth rates are around 13-14%, albeit form a low base. However, it is unlikely to eclipse fertilizer uses for phosphates in the medium term and is more of a niche rather than a major new use for phosphate. By 2030, demand for lithium iron phosphate for battery production is expected to be around 2.0-3.5% of overall phosphate demand, depending upon the share of the battery market that LFP eventually claims. Fertilizer will still represent the lion's share of phosphate demand going forward.

However, the rare earths content of phosphate projects is also attracting attention. Sedimentary phosphate deposits can contain considerable amounts of accompanying rare earth elements (REEs), which are needed for electronics and in renewable energy production. The demand for REEs is expected to grow four to six times over the next two decades. Most wind turbines use magnets which contain neodymium and praseodymium to strengthen them, and dysprosium and terbium to make them resistant to demagnetisation. Phosphate rock containing rare-earth elements (REEs) is considered one of the most promising potential secondary sources of REEs and extraction of them could be a useful side income stream for new phosphate projects and a way of tipping them into profitability.

Resource constraints?

In spite of annual fluctuations, over the long term phosphate demand has continued to grow at a steady rate this century, averaging 2.1% year on year over the period 2000-2022. Although there are indications that the long term growth rate is slowing as markets mature and there is increased concern over overapplication of phosphates, this may mean an average growth rate of 1.5% year on year over the next decade or so, equivalent to around 3.5 million t/a of phosphate rock, or one large scale mine per year.

The steadily increasing demand for phosphate and uncertainty about the size of phosphate reserves have driven a concern that humanity may be running out of one of its key resources. Drawing a comparison with the depletion of oil reserves and the famous Hibbert Curve of 'peak oil' production, some scientific papers have even raised the spectre of 'peak phosphorus' and the idea that some time over the course of the 21st century we may find ourselves running out.

Worries over 'peak oil' production were very common in the 2000s, but have fallen away as shale drilling opened up new reserves and more efficient vehicle engines the transition to electric drive trains has led to demand plateauing and soon probably falling. Indeed, the peak oil concern for the industry now is one of demand rather than production and a transition away from oil. However, with phosphorus the concern never seems to have quite gone away in spite of more recent surveys of rock reserves showing potentially hundreds of years of resources. In 2010, IFDC geologist Steven Van Kauwenburgh estimated the world's supply of phosphate rock at 60 billion metric tonnes in World Phosphate Rock Reserves and Resources, and another survey by Argus and the International Fertilizer Association (IFA) was published in March 2023 which found that, despite reports in some quarters to the contrary, there is no global shortage, and that there are sufficient deposits of mineable and processable phosphate rock for about 350 years' supply at projected usage rates and using current technology. This figure assumes no advance in mining and processing technology from the present day and can be seen as a low-ball estimate. In theory, if total available global resources are considered, more sustainable farming practices are more widely adopted and fertilizers are used in an increasingly efficient way, a higher-end limit could be more than 1,000 years. There is no absolute resource constraint on phosphorus that we need worry about this century.

Deglobalisation

However, while reserves are plentiful, their distribution and cost do remain concerns. The five-fold increase in the price of phosphate fertilizer that happened in 2008 led to a major – albeit temporary - fall in demand worldwide. The price spike was caused by a number of factors. These included an imbalance between supply and rapidly expanding demand, especially in Asia, and the growing demand for fertilizers to be used for biofuels to replace oil in the US, Brazil and Europe. But some have pointed to the concentration of phosphate resources as a potential worry in its own right.

As Figure 1 shows, 80% of the world's current annual phosphate supply is concentrated in six countries; China, Morocco, the US, Russia, Jordan and Saudi Arabia. Phosphate reserves, meanwhile, are even more concentrated, with 83% concentrated in North Africa and the Middle East, as shown in Figure 2, and 69% in Morocco alone. And as far as phosphate trade goes, 70% of trade is supplied by Morocco and the Middle East (mostly Egypt, Jordan and Saudi Arabia). This is far more concentrated than the market for oil, which even with the addition of Russia to OPEC+ only controls around 40% of world oil production, and 60% of trade (although 80% of reserves, mainly in the Middle East). The spectre of an 'OPEC for phosphates' has been raised by the major changes in the world economy and geopolitics of the past decade or so, with a retreat from the globalisation that drove world growth in the 1990s-2000s and a move to what the World Economic Forum has called deglobalisation, something that has been accelerated by the covid pandemic and the war in Ukraine. In the phosphate industry, Chinese protectionist measures such as its export ban has also helped change the global phosphate trade. This is potentially a worry for major importing regions such as India, Europe and Brazil. It is worth saying that there is no sign that governments in e.g. Saudi Arabia, Morocco or Jordan are trying to cartelise the phosphate market. Nevertheless, there is a policy drive in some countries to try and secure control over supply.

Diversification of the supply base depends upon a number of 'junior' phosphate mining projects in countries such as Australia, Canada, Brazil and South Africa. Brazil, for example, is looking to reduce import dependence on phosphates. Following the outbreak of war in Ukraine it has introduced a National Fertilizer Plan in 2022, and the Tres Estradas project received a construction license and secured funding later that year. Of the $40 billion expected to be invested in mining in Brazil over the period 2022-26, 15% is earmarked for phosphate projects. In South Africa Kropz is developing two major phosphate projects; at Elandsfontein, on South Africa's west coast, which is nearing production, and Hinda in the Republic of Congo. South Africa's Afrimat has also acquired the Glenover phosphate project in South Africa and is looking at developing both rare earths as well as phosphates from the project.

There are also considerable reserves in Quebec, Florida, Kazakhstan and Togo, as well as Brazil, where Vale and Anglo American each hold significant phosphate interests. Other phosphate mining countries include Peru and Mozambique. In Canada, last year, the Quebec environment ministry gave the go-ahead to the $750 million Arnaud phosphate mining project.

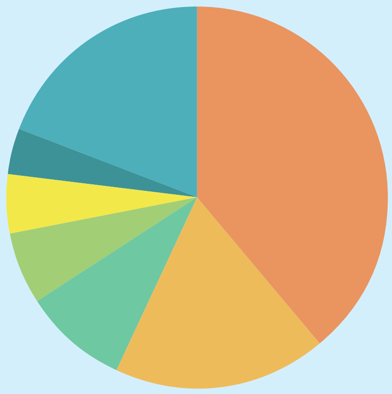
Over the next decade several of these projects are likely to come to fruition, with attendant downstream fertilizer production and sulphuric acid demand in new regions for the phosphate industry.

Environmental issues

Other concerns over phosphates are environmental. There are several strands to this. One is based around the unsightliness of phosphate mines and the disruption to the surface environment that they cause, although most are reclaimed and remediated at the end of their lives. Nevertheless, this has driven some opposition in places such as the US, and perhaps been a factor in the phosphate industry being constrained in developing new capacity there and instead decamping to countries where the government perhaps has to pay less attention to local concerns.

Phosphate mines also produce large amounts of phosphogypsum tailings, and because there is naturally-occurring uranium, thorium and radium found in phosphate rock this ends up in this waste and

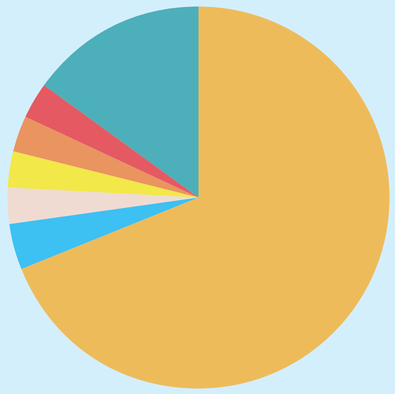
Figure 1: **Phosphate production by country, 2022**



China	**39%**
Morocco	18%
USA	9%
Russia	6%
Jordan	5%
Saudi Arabia	4%
Rest of world	19%

Source: USGS

Figure 2: **Phosphate reserves by country, 2022**



Morocco	**69%**
Egypt	4%
Tunisia	3%
Algeria	3%
China	3%
Middle East	4%
Rest of world	19%

Source: USGS

can make it very mildly radioactive. This has limited the use of phosphogypsum as a construction material in Florida and meant that miners there must maintain large gypsum stacks, although there have been recent moves by both federal and state governments to authorise its use. A study is due to report back in April 2024, but again this has constrained US phosphate development and expansions even at existing mines.

In Europe, the concern has been around cadmium, which can also be found in phosphorite and apatite rocks and which can end up in phosphate fertilizers and via them the food chain. The EU has set a limit on cadmium in phosphate fertilizers at 60 mg/kg from July 2022, and some member states have sought to set the limit lower still, reducing to 40mg/kg after three years and to 20mg/kg after 12 years. However, this would have effectively prohibited use of phosphates from Morocco and North Africa – responsible for 70% of EU imports – and privileged use of Russian phosphate, which has much lower levels of cadmium. The EU was unable to agree on the lower limit, but in 2019 did to publish new guidelines which allow labelling of phosphate products which are low in cadmium. One of the fallouts from the Ukraine war and sanctions on Russia has been to very much push this debate to the 'back burner' in the EU.

The circular economy

But perhaps the greatest environmental concern regarding phosphate fertilizer use is that of eutrophication – leaching of phosphates into water courses and causing algal blooms which remove oxygen from the water and cause damage to marine ecosystems. The Food and Agriculture Organisation of the United Nations (FAO) estimates that only 15 to 30% of phosphorus in fertilizers is actually taken up by plants in the year of its application. This can vary considerably due to different types of soil and their ability to bind phosphorus, making it unavailable to the plant.

Increasing phosphorus nutrient use efficiency is perhaps the most obvious way to tackle this, but increasing phosphorus use efficiency (PUE) is not a simple matter, and can range from increasing root presence in the uppermost part of the soil (which tends to be highest in P) to using varieties of crop with better uptake. Some areas have a surplus of P in the soil, while others, often in poorer soil areas, often have a deficit – up to 50% of soils are reckoned to be P-deficient globally. Obviously greater use of P in P-deficient soils and less in P-surplus soils would lead to greater PUE, but this might still lead to a reduction in yield in those P-surplus areas. Effective capture and recycle of animal manures in mixed livestock-cropping systems could also help move some regional P deficits closer to net zero P balances, particularly in forage croplands with extensive P deficits. But achieving more effective manure P recycling at the global scale may require broader management or structural changes in livestock farming, such as improved access to manure collection and treatment technologies, changes in livestock diets, or even reductions in livestock densities.

There have been some moves in recent years, especially in countries like the Netherlands which have particular problem with phosphate leaching and eutrophication, to attempt to capture and recycle phosphorus as part of a move towards the 'circular economy'. Phosphorus recovery at waste water treatment plants is an emerging technology, but the economics are hampered by the fact that it is much more (up to six times more) expensive to recover phosphorus from large quantities of low-phosphorus sludge than to extract from smaller quantities of higher-phosphorus ore. It is also overall a more carbon-intensive method of phosphate production than mining. The phosphorus recovery rate from waste water can reach up to 40-50% with current technologies, while recovery rates from sewage sludge and sewage sludge ash can reach up to 90%. However, few of these methods have been demonstrated on an industrial scale. Phosphate mining will likely remain as the main supply of phosphorus for the foreseeable future.

Alternative techniques

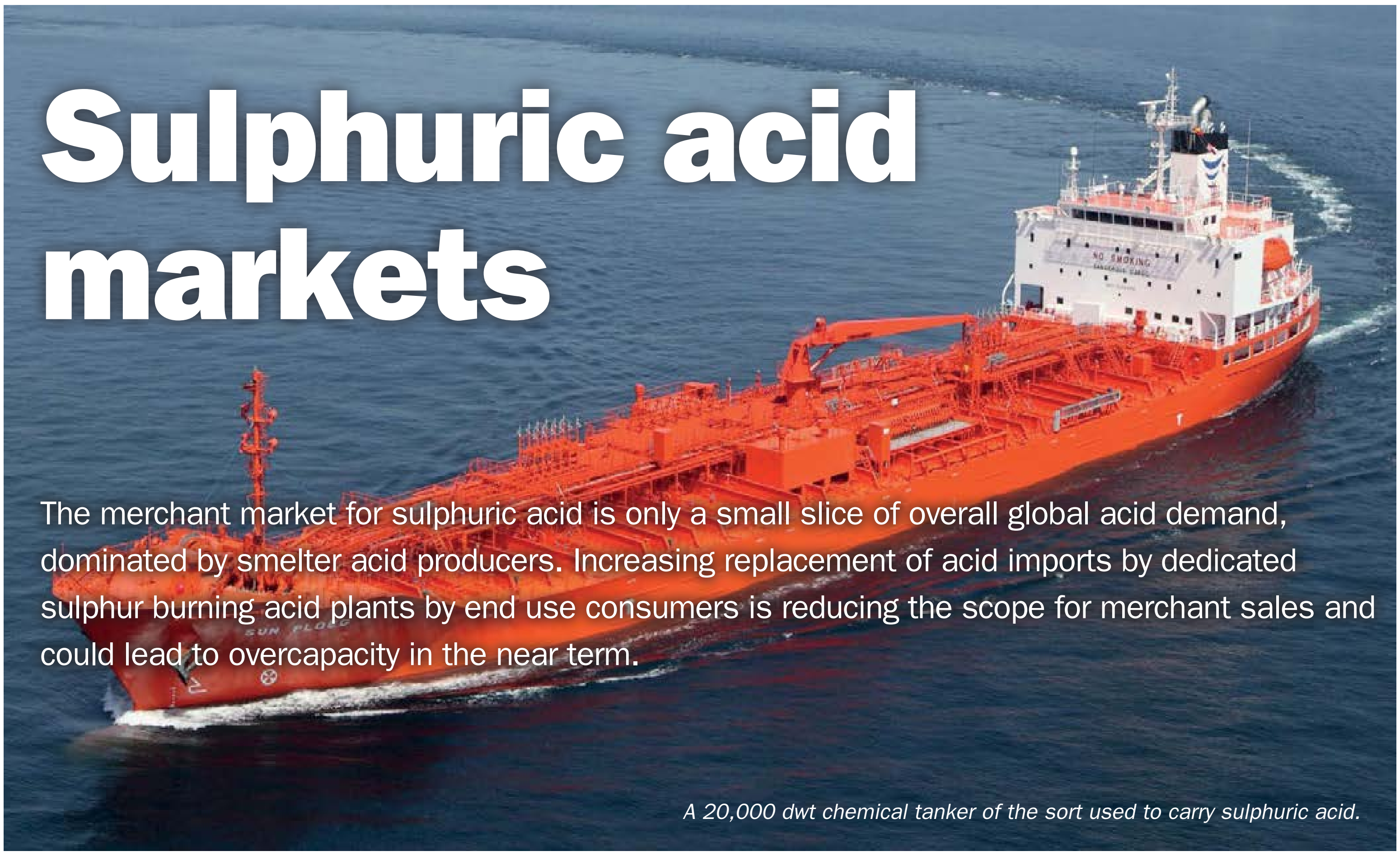
While most (>80%) phosphoric acid is produced today via acid treatment of phosphate rock, other methods are available. It can be produced via thermal treatment of rock, which generates acid of a higher purity for the manufacture of high grade chemicals, pharmaceuticals, detergents, food products, and other non-fertilizer products. Most thermal processes involve the addition of steam to the phosphorus burner to produce and maintain a film of condensed polyphosphoric acids which protect the stainless steel burner tower. The products from the burner tower pass directly into a hydration tower where the gaseous phosphorus oxide is absorbed in recycled phosphoric acid. Alternatively, the phosphorus may be burnt in dried air. The phosphorus pentoxide is condensed as a white powder and separately hydrated to phosphoric acid. This method allows heat to be recovered and reused.

However, thermal production of phosphoric acid is much more energy intensive than wet phosphoric acid production, and correspondingly more expensive, and as long as sulphuric acid remains relatively cheap, they are unlikely to make much inroad in phosphate fertilizer production where the purity requirements are lower.

More of the same

Recent disruptions to the traded phosphate market caused by sanctions on Russia pushed up prices in 2022 and led to a major fall in consumption last year. However, this year is expected to see a rebound in demand and overall the long term trend in increased fertilizer demand for phosphate remains unchanged. Brazil has a rising planted area and higher cash crop yields, and India is likely to remain a major consumer and importer, with moves to more balanced nutrient application supporting future growth in phosphate demand. At the same time, Chinese export capacity remains constrained by the government's determination to ensure continuity of domestic supply by whatever means necessary, while continuing to bear down on more polluting and less efficient domestic capacity.

There may be an increased push towards some new projects outside of traditional growth areas like Morocco and the Middle East, driven by concerns over supply security, such as in Brazil. The Arianne Resources Lac a Paul phosphate project is also due to come on-stream in Canada in 2026. There are also indications that China is becoming concerned about its remaining phosphate deposits and may be content to see cuts in downstream capacity over the medium to longer term in order to preserve domestic reserves. However, in spite of some geographical shifts in phosphate production, and side-streams like rare earths recovery, the basic formula of phosphate mine, and sulphuric acid-based fertilizer production looks unlikely to change significantly over the next two decades or more.



Sulphuric acid markets

The merchant market for sulphuric acid is only a small slice of overall global acid demand, dominated by smelter acid producers. Increasing replacement of acid imports by dedicated sulphur burning acid plants by end use consumers is reducing the scope for merchant sales and could lead to overcapacity in the near term.

A 20,000 dwt chemical tanker of the sort used to carry sulphuric acid.

PHOTO: CLEAN MARINE

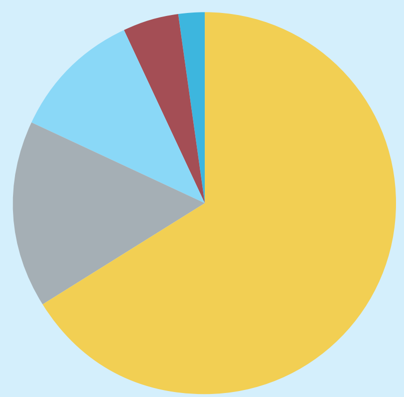
Sulphuric acid prices have been through a turbulent couple of years, with prices rising steadily through 2021 and remaining at high levels for much of 2022, before beginning a price collapse that has only turned around in the past couple of months.

Global sulphuric acid production of around 270 million t/a is dominated by sulphur burning acid capacity, with around 30% coming from the off-gases from smelting of base metals; mainly copper, but also lead, zinc and to a lesser extent nickel. Because it is involuntary production to avoid emissions of harmful sulphur dioxide, production of smelter acid is driven primarily by the economics of metal markets rather than sulphuric acid prices, and hence it is often produced regardless of prevailing acid market conditions. As Figure 1 shows, smelter acid capacity is concentrated in Asia, particularly China. In 2022, China accounted for almost 50% of world copper smelter production, followed by Japan (7.4%), Chile (5.2%) and Russia (4.6%).

The difficulty and hence high cost of shipping sulphuric acid means that sulphur-burning acid capacity is usually integrated into local downstream uses, especially phosphate fertilizer production, but also copper and nickel leaching etc. Domestically and internationally traded acid thus tends to come mainly from smelter acid production, with sulphur burning acid capacity adding to this when prices permit. In 2022, seaborne sulphuric acid trade was only 16 million t/a, a fraction of the huge market for sulphuric acid, and CRU estimates that 12.8 million t/a of this (80%) was accounted for by smelter acid, with sulphur burnt acid making up the remaining 20%.

This creates a dynamic between sulphur and sulphuric acid prices. Where sulphuric acid prices are higher than the equivalent volume of sulphur, there is an incentive for consumers to import acid rather than sulphur. Conversely, low sulphur prices are often a signal for those who have the capability to burn sulphur instead of importing acid to start up their sulphur burning acid plants, which can also often generate electricity credits. Much of the fall in acid prices during 2022 and 2023 was due to falling sulphur prices, which had peaked at around $500/t in mid-2022, only to drop quickly to below $100/t within months. This fed through into, for example, a significant reduction in Moroccan imports of acid, especially from Europe. At the same time, significant volumes of acid were available from China, helping to push prices down.

Figure 1: **Smelter acid production by region, 2022**



Asia	67%
Europe	16%
Americas	11%
Africa	5%
Oceania	2%

Source: ICSG

The past couple of months, however, have seen something of a turnaround in acid prices, as Morocco has returned to the market, taking available volumes and leading to something of a supply squeeze as spot cargoes became unavailable.

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

Table 1: Largest sulphuric acid importers, 2022, million t/a

Chile	3.7
United States	3.2
India	2.1
Turkey	1.7
Philippines	1.5
Morocco	1.3
DRC	1.2
Brazil	1.0
Thailand	0.7

Source: WITS

This has been driven by a buoyant phosphate market, with phosphate prices rising around 20% during 3Q 2023. Demand has been rising from Chile, helping to bring acid prices upwards again.

Demand - major importers

As Table 1 shows, the major importers of sulphuric acid in 2022 were Chile at 3.7 million t/a, followed by the United States and India. As noted, Morocco's imports were significantly down on 2021.

Chile

Chile's acid demand is almost all destined for copper leaching projects. Chile has the largest copper leaching operations in the world. However, demand has been falling due to the exhaustion of some projects and falling ore grades, while there has been a renewed increase in copper smelter projects. Chilean demand for sulphuric acid for copper production was 8.4 million t/a in 2022, and this is expected to fall to 8.2 million t/a this year. However, some mine life extension programmes and new leaching projects are expected to more than make up for the decline of existing projects and boost Chilean acid demand over the next few years, up to 8.3 million t/a in 2024 and back to 8.4 million t/a in 2027.

On the other hand, interruptions in domestic smelter production mean that Chilean acid imports were 3.7 million t/a in 2022; a record figure, and up significantly from 3.3 million t/a in 2021. Of this, around 1.1-1.2 million t/a of imports comes from copper smelters in neighbouring Peru, and this figure has been fairly constant for at least a decade and there is at present no real prospect of this changing in spite of some controversial copper smelter projects in Peru like the now shelved Tia Maria project. The upshot is that additional Chilean acid demand of around 1.7 million t/a must be supplied from outside the region. Mostly this comes from East Asia, but when prices are right European acid can also make its way to Chile. There are complications with this related to freight prices however, and recent congestion in the Panama Canal has forced European acid shipments to travel around Cape Horn, adding 10 days onto shipping times and increasing freight costs accordingly.

The ageing Ventanas smelter was decommissioned in May 2023, removing 450,000 t/a of domestic acid production. However, Chile also continues to build domestic sulphur burning acid capacity, which will reduce the scope for long-distance shipments to Chile over the medium term, from around 2.6 million t/a at present to 2.0 million t/a by 2027.

United States

The US exports some sulphuric acid, mainly to Canada and Mexico, however it is mainly a net importer, to the tune of around 2.6 million t/a per year. Most of this goes to feed phosphate production in Florida. A downturn in US phosphate production reduced US acid demand in 2022 to about 31 million t/a, though domestic acid production also reach a low point of 28.2 million t/a. US domestic acid production is now on a rising trend, however, with both some incremental smelter capacity and new sulphur burning acid plants to feed copper and lithium mining operations. At the same time, these mining operations are also boosting overall demand, and the volume of US imports is expected to remain relatively even over the coming years at just under 3 million t/a.

India

Indian acid demand was 13.4 million t/a in 2022, mainly for phosphate production. Of this, domestic sulphur burning acid plants supplied 9.1 million t/a and domestic smelters 2.4 million t/a. The acid situation in India continues to be significantly impacted by the forced shutdown of the Sterlite Copper smelter at Tuticorin. Tuticorin had 1.2 million t/a of acid capacity, and its absence has led to increased Indian imports of acid to make up for the shortfall.

Indian acid capacity is increasing. Coromandel started a new 0.6 million t/a sulphur burning acid plant in August this year, and Iffco are due to start a new sulphur burning plant of similar size in Q1 2024. Paradeep Phosphates is also building a 0.5 million t/a acid plant which is due to be completed at the end of 2024 or start of 2025. In addition to this 1.7 million t/a of capacity, Adani has a new smelter due to start production next year which will add another 1.5 million t/a of sulphuric acid capacity. By 2027, Indian acid production is forecast to be 15.8 million t/a, up 3.9 million t/a on 2022. As with the US, additional demand is expected to keep pace with capacity additions, however, and imports are not likely to fall much on their current levels.

Morocco

Morocco imports acid to feed its rapidly growing phosphate industry. Moroccan phosphate capacity is rising from around 20 million t/a in 2018 to about 32 million t/a in 2025-6. But at the same time, the country is building sulphur burning acid capacity to cover the additional requirement for acid, and in fact Moroccan imports are likely to fall from around 2 million t/a in 2021 to closer to 1.2 million t/a over the medium term.

Supply – major exporters

As Table 2 shows, the largest exporters of acid in 2022 were China, followed by Japan, the European Union, South Korea, Canada and Peru.

China

China exported a major volume of acid in 2022; 3.6 million t/a, making the largest global exporter that year. However, Chinese acid exports in 2023 have been down significantly, with lower prices deterring sulphur-based acid producers from entering the export market, and smelters finding opportunities for acid sales on the domestic market. Chinese f.o.b. acid prices have dropped to only just above zero, with domestic prices around $50/t. The third quarter of 2023 did see an uptick in Chinese exports of acid nevertheless, with Indonesian demand high in Q2 and Q3. Overall,

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

Table 2: Largest sulphuric acid exporters, 2022, million t/a

China	3.6
Japan	3.1
European Union	3.0
South Korea	2.7
Canada	1.9
Peru	1.1
Zambia	0.8
Mexico	0.7
United States	0.6

Source: WITS

Chinese exports are expected to be 2.3 million t/a of acid for full year 2023.

Copper smelting in China expanded dramatically over the period 2005-2015, and Chinese acid production doubled over that period. While there has been a period of rationalisation since then, with a crackdown on energy-intensive industries as part of the country's aim to reduce its carbon emissions, and a focus on greater reuse of copper scrap and reduced condensate imports, new smelter capacity continues to increase. Daye Nonferrous and Nungua Copper will add 2.0 million t/a of acid capacity this year and Jinchuan Copper 1.2 million t/a next year.

Japan and Korea

Japan and South Korea continue to be major exporters of sulphuric acid from their smelting industries.

Korean exports are expected to remain at around 2.6-2.7 million t/a of acid over the next few years, and Japan around 3.1-3.2 million t/a. Output is expected to be down slightly overall for 2023 due to 4Q maintenance turnarounds at Japanese smelters, removing up to 280,000 tonnes of acid from the market.

Europe

The other major acid exporting region is Europe. Acid exports used to be typically around 4.0 million t/a, with Bulgaria, Germany and Spain among the largest producers, but 2022 saw a wave of maintenance shutdowns at smelters and also high power prices which led to some smelters working at reduced capacity for economic reasons, so exports fell to 3.0 million t/a. The figure for 2023 is expected to be slightly higher, with for example the Ecobat smelter in Germany resuming operations in March 2023.

Others

Acid demand is rising rapidly in Indonesia for HPAL nickel production. Demand will more than triple to 17.0 million t/a to 2027. Most of this will be supplied by domestic sulphur burning acid capacity, however, which is set to rise from 3.9 million t/a in 2022 to 12.8 million t/a in 2027. New copper smelting capacity will take Indonesian smelter acid production to 3.2 million t/a in 2027, and another 1.1 million t/a may come from pyrite roasting. All of this could actually turn Indonesia into a net acid exporter, though only a marginal one. In the short term however, it has led to increased acid imports, up to 564,000 tonnes in 1H 2023, mostly supplied from China.

Africa's Democratic Republic of Congo is seeing a new copper smelter being constructed at Ivanhoe Mines' Kamoa-Kakula copper mining complex. The smelter will produce 500,000 t/a of copper at capacity, and is scheduled to open in 2025. Vedanta is also looking to build a new zinc smelter at its Gamsberg zinc mine, near Aggeneys, in South Africa. The project would produce 300 000 t/a of high-grade zinc by processing 680 000 t/a of zinc concentrate, generating 450,000 t/a of sulphuric acid for both export and consumption within South Africa.

Oversupply looming?

Smelter acid is continuing to increase its share of global sulphuric acid trade. As smelter operators see sulphuric acid almost purely as a waste product, this could help to keep acid prices subdued. At the same time, there is new sulphur burning acid capacity coming onstream in traditional import markets such as India, Chile and Morocco which are reducing the need for long distance acid shipments. Merchant trade in acid is forecast to fall from 16 million t/a this year to 14.4 million t/a in 2024, and may not begin to rise again until 2028. There is therefore the potential for oversupply in the market over the next few years. On the other hand, phosphate markets appear to me moving into deficit, which could help boost sulphur and acid prices going forward.

Sulphur + Sulphuric Acid 2023

A report on CRU's annual Sulphur + Sulphuric Acid conference, held in New Orleans, USA, 6-8 November 2023.

Fireworks in the French Quarter, New Orleans.

PHOTO: FRANCKREPORTER/ISTOCKPHOTO.COM

CRU's 39th Sulphur + Sulphuric Acid Conference and Exhibition convened in New Orleans, 6-8 November 2023, with more than 400 delegates in attendance. This year the programme was enhanced by having more panel discussions, promoting greater interaction between attendees and speakers. A key feature on the morning of the first day of the agenda was the troubleshooting clinics, one on sulphur recovery moderated by Elmo Nasato of Nasato Consulting and the other a troubleshooting clinic for sulphuric acid plant operators run by Steve Puricelli of EXP, Hannes Storch of Metso, Stuart Hinze of JR Simplot and Hanno Hintze of Aurubis. The rooms were packed with attendees keen to learn from the experts and share their experiences. In addition, following the success of the short 15-minute technical showcase presentations introduced at last year's conference, the technical showcases returned this year with an expanded programme of presentations covering sulphur and sulphuric acid process technology and equipment.

Market papers

On Monday afternoon the conference proper began with a review of the major markets, beginning with a review of the US economy by Keith Belton of the American Chemistry Council. Inflation remains an issue for the world economy, he said, with an average of 5.9% this year slowing to 4.4% next, and interest rates slowing growth. Global GDP is expected to rise by 2.6% this year and slow further to 2.4% next. The strong dollar and high oil prices are also an issue for energy importing nations like Europe and China. The industrial sector is worst hit. Global manufacturing indexes have been in decline for the past two years. China also faces its debt-ridden property sector and weaker global demand for goods. Oil production growth is slowing, rising to just over 102 million bbl/d next year, with a considerable overhang of capacity.

In the US, there is considerable uncertainty over the economy, with a retrenchment in consumer spending and falling goods demand, and though inflation is also falling, it remains stubborn, and the risk of recession remains high. US chemicals demand has been relatively weak this year, with most sectors seeing a fall in domestic demand and considerable destocking. But US oil and gas output continues to be a bright spot, with increased demand in Europe due to the loss of Russian output. Refinery utilisation factors continue to be at around 90%, and gas-based chemicals like ammonia and methanol continue to be globally competitive. He also highlighted the potential burden of increased regulation on the industry, but conversely, the Inflation Reduction Act has helped galvanise new project activity.

Next came the ever-popular sulphur market presentation, delivered as usual by CRU's Peter Harrison. The past 12 months, he said, had seen sulphur prices swing from overperforming to underperforming, from highs of over \$400/t f.o.b. Middle East in mid-2022 to around \$90/t at present. Looking to the next few years, he predicted that sulphur demand for phosphate production was

PHOTO: CRU

A lively ask the experts panel discussion on supply and demand dynamics in an era of energy transition. L-R: Viviana Alvarado (CRU), Peter Harrisson (CRU), Aaron Wade (Exawatt), Kaitlin Gebbie (CRU), Brendan Daly (CRU), Angie Slavens (UniverSUL Consulting).

likely to plateau in China and the US, but Morocco will see large incremental demand for its phosphate projects; up to 3 million t/a from 2022-2028, with additional demand also coming from Saudi Arabia. The market rebound and strongest additions are likely to be in 2023 and 2024. A recovery in the phosphate market will be followed by additional demand for lithium processing in the US at the same time that refinery closures or conversions reduce sulphur output, leading to more US import demand. Refining also continues to add Chinese sulphur production, leading to import demand narrowing by around 2 million t/a over the forecast period. Meanwhile Indonesia's fast growing nickel industry could add another 4 million t/a of sulphur demand. Overall Peter therefore saw the sulphur market moving into deficit from next year, with additional production cuts in Europe and the US only partially offset by new supply in the Middle East, and strong demand growth in Morocco and Indonesia, driving average global prices higher in the longer term, although stocks in China and Saudi Arabia may cushion markets in the short term. The traded sulphur market could reach 44.8 million t/a by 2028, with the UAE increasingly dominant on the export front. Looking beyond the end of the decade, the coming phaseout of oil could still be matched by new sour gas sulphur at least to the 2040s, when a deficit could emerge.

The sulphuric acid paper was presented by Viviana Alvorado of CRU. Acid demand growth has been boosted by Indonesia's need for acid for minerals processing, allowing Chinese producers to decide when they wish to export. New Chinese smelter capacity is adding 3 million t/a more acid to the mix this year and next. Across the Pacific, Chile is seeing increased demand for acid for copper and importing around 3.7 million t/a this year. As previously mentioned, US lithium production will also see North American acid demand increase, though most of this will be met by local sulphur-burning acid plants. In general, increased supply integration, i.e. building domestic acid capacity, is likely to limit global acid trade requirements over the next few years. Seaborne acid trade is falling from 16 million t/a in 2022 to 14.4 million t/a in 2024. This is likely to mean less sulphur-burnt acid on the market, giving smelter acid a greater share and possibly bringing down prices as a result.

Brendan Daly of CRU presented the phosphate market paper. Phosphate prices have broadly declined from their 2022 peak due to weaker demand and easing supply disruption, but there has been an uptick in the second half of 2023 towards $600/t c.fr for MAP/DAP. Chinese phosphate exports were higher year on year for Q1-Q3 2023, but have slowed due to renewed export restrictions, with Morocco's new capacity not yet making a difference to the market. In India, a significant (31%) cut to the DAP subsidy is expected to impact upon demand for the remainder of this year and into 2024. On the production site, US phosphate production continues to decline due to falling rock grades. Court cases on countervailing duties against phosphate imports from Russia and OCP have found in favour of the overseas companies, which may help lower US prices. New phosphate capacity is still mostly (ca 75%) coming from Morocco and Saudi Arabia, but net demand growth appears to be running ahead of capacity, leading to a deficit by 2027. Lithium iron phosphate demand for batteries is growing rapidly, and could reach 2 million t/a P_2O_5 by 2030, though it remains concentrated in China for now. Overall, Brendan saw prices likely to correct lower in the short term before rebounding in the medium-longer term.

The Flexim stand, one of the many exhibits attracting the attention of delegates.

The last of the afternoon's market presentations was given by Aaron Wade of CRU's new Exawatt purchase and consultant Kaitlin Gebbie, and addressed challenges and opportunities for sulphur in the energy transition. The rapid expansion of battery use is an upside for sulphuric acid demand. Sulphuric acid is needed for nickel sulphate, and both lithium and phosphate for LFP. Total demand will depend on which technologies win out. For example, lithium can be recovered from brine processing, mineral processing or sedimentary processing. The latter are carbonates and so typically require much more acid, up to 45 tonnes per tonne of lithium carbonate recovered. Thacker Pass and Rhyolite Ridge may add 2.8 million t/a of acid demand in the US by 2028. However, environmental concerns may discourage leaching use and tailings disposal.

Sulphur technology

Tuesday's sulphur technology strand began with a paper by Alex Geiss of AMECO on his company's recently constructed 2,000 t/h sulphur reclaimer for Keyera at South Cheecham in Alberta, Canada, one of the largest sulphur handling operations in the world. The setting makes for cold weather operating challenges during winter when temperatures can fall to far below zero, and the portal reclaimer also had to handle prilled sulphur and minimise dust emissions.

Richard Barrington of AMETEK/Controls Southeast described a predictive method developed for estimating the liquid level in sulphur run-down lines. It is critical to maintain an open vapour path from the condenser to the sealing device, he said, and CSI has observed problems in the field which appear to be caused by undersized run-down lines. Testing of the method against measured values has led to a set of formulas that can be used for calculating the liquid levels.

Ulrich Nanz of IPCO described the company's two main forming technologies; the *Rotoform* pastillation process and the drum granulator, and their suitability for different throughputs, cleaning requirements, as well as formed product strength and water content.

Two panel sessions rounded off the first sulphur session; on safe and effective sulphur forming and handling, and on emissions from sulphur tanks and sulphur pit degassing.

Operator case studies

ENAP in Chile contracted Worley Comprimo to conduct a technical audit of the sulphur recovery section of their Aconcagua refinery on the Pacific coast. Marco van Son of Worley Comprimo described the approach to this and the steps taken to improve reliability and lower SO_2 emissions.

Petronas revamped their refinery SRUs in 2010, since when they have been dealing with hotspots in the thermal oxidiser combustion chamber, leading to refractory failures and frequent maintenance shutdowns. Although some interim measures had been taken, the problem had not been resolved. Mohammad Azahar Ahmad of Petronas explained the issues and presented the findings of a technical review in 2021 which has made recommendations for tackling the problems on a long term basis.

Scott Kafesjian of Wood Group also tackled the subject of rejuvenating an old SRU with reference to a US refinery with a 46 year old SRU. Rather than scrapping and replacing the unit, Wood was able to modernise the unit and improve safety, reliability, operability, and recovery efficiency of the redundant SRU, thereby providing the owner confidence that refinery throughput would not be compromised by a sulphur recovery unit outage.

SRU design

A short session on Tuesday afternoon looked at issues in SRU design. New designs and retrofits of existing waste heat boilers (WHBs) are increasingly being used to generate higher pressure steam to accommodate higher heat loads, leading to increased operating issues, especially in kettle-type designs, where feedwater injection and internal recirculation are key attributes of shell-side performance. Elmo Nasato presented the results of some simulations to better understand the effects of feed water distribution on vapour hold-up in a kettle-style WHB. Appropriate placement and distribution of feedwater into the shell-side of the WHB can significantly reduce vapour hold-up within tube bundle regions undergoing high heat flux.

Marcus Weber of Fluor covered lessons learned from an owner/licensor perspective in the design and construction of several 500-1000 t/d multi-train sulphur recovery unit/tail gas treating unit projects. Structuring project execution in the right way between the licensor, owner and EPC contractor can lead to lower project execution risk in terms of cost and time and lower capex and opex cost.

Again a panel session on sulphur plant design closed out this section.

SRU innovations

Alina Green of WIKA presented her company's sapphire-protected thermocouples for temperature monitoring in SRUs. WIKA have now adapted this technology for low pressure Claus applications and included a secondary containment system that is pressure tested to 100 bar.

Axens has recently developed a new titania-based catalyst called CRS 41, which has much higher porosity than previous generations of the catalyst while preserving mechanical integrity. As described by Johann le Touze of Axens, this facilitates the conversion of COS and CS_2 at low temperature, which is essential if hydrocarbons are present in the acid gas feed.

As environmental SO_2 emission regulations become more stringent, Tail gas treating options become limited.

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

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

To potentially achieve lower opex, using a biological desulphurisation process as an alternative is becoming of increased interest. At the same time, demands for increased SRU capacity and reliability favour the use of medium and high-level oxygen enrichment. Fluor recently evaluated revamp options for an existing refinery with 3 x 100 t/d SRUs. Fluor's COPE®II Oxygen Enrichment technology was selected to increase each train capacity to 150 t/d, with Thiopaq O&G bio-desulphurisation technologies used to achieve an H_2S treated gas specification of <25 ppmv.

PHOTO: CRU

L-R: Dirk Riethe (Bullco) and Hannes Storch (Metso) at the welcome reception.

With the emerging greater application of bio feedstocks in refineries there is a growing need to operate SRUs at much lower capacities than originally designed and with almost continuously fluctuating acid gas compositions. These changes have a detrimental effect on the ability to control the SRU with fixed air-to-acid-gas ratios. Gerton Moelnar of Worley Comprimo described improvements to the Advanced Burner Control System – 2ACT – which incorporates and AMETEK analyser upstream of the SRU for continuous sampling and monitoring of the gas stream to dynamically change burner operation in fluctuating gas streams.

The changing sulphur industry

A final sulphur session on the last day looked at the future of the sulphur industry. David Savage from Matrix PDM Engineering considered ways in which supply and demand changes in the sulphur industry will create a need for expansion in sulphur infrastructure. Next a paper presented by Christian McDermott of Voovio Technologies and co-authored with Angie Slavens and Elmo Nasato highlighted the skills gap; a growing issue in many industries in the US and worldwide. Industrial manufacturers are losing experienced employees and the knowledge they have in their heads, built up over decades, is rarely written down or transferable. This leads to lack of standardisation in procedures and training, and can open up risks around incidents and production losses. The paper looked at how manufacturers can close these gaps using digital tools, in particular knowledge automation.

Sulphuric acid technology

The sulphuric acid session also began with papers looking at the ways that the industry may need to change in future. The energy transition is demanding more metals for batteries and electrical items, but simultaneously forcing a look at recycling and the 'circular economy'. Marcus Runkel of Metso used recovery of metals from pyrite tailings using Metso's fluid bed roasting process, and expanding its capacity from the previously typical 1,000 t/d of concentrate via the "Circoroast" process. This allows for larger throughput, due to the flexibility in the heat balance of the roaster and a more compact plant footprint.

Joan Fedderson and Samuel Johanssen of Topsoe presented the wet sulphuric acid (WSA) process as a way of treating lean SO2 concentrations in waste streams without the need for scrubbers. In the pulp and paper industry, WSA also increases the circular use of chemicals such as sodium and sulphuric acid, while in a refinery, the it can lead to a significant saving in CO_2 equivalent compared to a Claus tail gas unit.

The years of covid forced the industry into new ways of operating. Collin Bartlett of Metso reflected on how the pandemic had changes structures of contracting and project execution, via remote working and digitalisation, and to what extent lessons learned during that time could or should become integrated into the way we work in future.

Catalysts and emissions

The pressure to reduce emissions of SOx and NOx is a constant one. Kassie Chanda of MECS reviewed emissions reduction options for acid plants. Scrubbing methods and mist eliminators can be employed for SO_2, SO_3 and acid mist removal, including regenerative and wet scrubbers for SO_2 removal. Nitrogen oxides can be converted to gases like nitrogen or soluble N_2O_5 through processes like selective catalytic reduction (SCR/SNCR) and ozone oxidation.

Martin Alvarez of Topsoe reflected on his company's caesium promoted catalyst VK-69 via a series of case studies which highlighted its increased acid production and reduced SO_2 emissions, and for challenging applications a new combination with VK38+ which can achieve even higher conversion levels or deal with specific bottlenecks that can be solved with extra activity.

The last of the trio of catalyst/emissions papers was presented by Alison Belgard of BASF, who described how 3-D printing of catalysts has allowed catalyst manufacturers to experiment with previously unattainable geometries. BASF's new X3D catalyst now has three industrial references and demonstrated that its higher active surface area results in better SO_2 conversion, lower pressure drop and savings in energy costs and sodium hydroxide consumption.

Acid plant design

Tuesday afternoons sulphuric acid session began with two papers on sulphuric acid converters. Steve Puricelli of EXP looked at choosing a converter design, with considerations ranging from stacked, staid and catenary configurations, cost/benefits of upgraded materials, when an internal heat exchanger is a good choice, and how various configurations affect reliability and maintenance.

Robert Crane of NORAM followed with two success stories in redesigning old converters. The first project required the re-design of a 3-bed into a 4-bed converter comprising two catalyst passes with each pass split into two parallel beds to meet a very aggressive project schedule. The second involved an old plant with two converters. NORAM and the client evaluated various replacement strategies, ultimately resulting in the decision to only replace the old 4-bed converter.

Clark Solutions described *DrySeal*™ a safer alternative for seal cups, required in candle filter mist eliminators, which is both self-draining and autosealing, easy to clean and install and does not require additional set-up steps.

Douglas Azwell of MECS next presented a new impaction-based mist eliminator called *Prime Impact*™, which offers equivalent or improved efficiency at higher throughput and the same pressure drop as traditional impaction beds, resulting in the ability to debottleneck existing towers or design new or replacement towers with smaller diameters, thus reducing investment cost.

Acid plant operations

OMV installed new PFA fluoropolymer liners in their WSA plant at their refinery in Schwechat to help with corrosion issues. The plant design was also revised to allow process monitoring in operation and separate plant components during a shut down. Johannes Derfler of AGRU described the reasoning behind the choice of materials and the impact on plant operations.

Blake Stapper of Messler related a revamp of a spent acid decomposition furnace to improve plant throughput. The solution entailed introducing oxygen in two steps, both as an enrichment to the combustion air and by direct injection into the furnace.

Roland Gunther of Steuler described a case study in the replacement of the upper part of a co-current flow quench tower resistant, pre-lined workshop fabricated equipment.

Jan Bond of Amafilter recounted a recent project where a sulphuric manufacturing plant wanted to extend the service life of their sulphuric acid production units from 16 to 24 months by reducing the solid content in their liquid sulphur. As the liquid sulphur was stored for an extended period in the storage tank, this poised a significant challenge for filtration. Amafilter® developed, designed and built a two-vessel skid-mounted ceramic cartridge filter system which polishes the liquid sulphur, reducing the solid content to less than 5 ppm. As a result, the catalyst lifetime and maintenance interval were increased to over 24 months.

Gas cooling and heat recovery

Two operators papers by Petrokemia Gresik, one by Domenica Misale of Industrial Ceramics and another by Nelson Clark of Clark Solutions closed out the final acid session. Gresik redesigned the economiser of their acid plant. The new design changed the configuration from a single-compartment to a dual-compartment, with different materials and tube types for each compartment, and improves heat transfer, reduces corrosion, and lowers the SO_3 gas temperature at the intermediate absorption tower inlet. They also modified their waste heat boiler after experiencing multiple failures due to leaking tubes positioned behind the ferrule on the hot side. The failure was resolved after modifying the ferrule by tapering its edge, effectively reducing gas turbulence.

Nelson Clark also highlighted his company's heat exchanger design, *SAFEHX®*, which uses two tube bundles containing process fluid and an intermediate inert liquid detained in the shell. The latter is not only a heat transfer facilitator but also a physical barrier keeping the reacting fluids from coming into ontact. The two tube bundle configurations lead to a thermal gradient in the tubesheet, one that must be accounted for to prevent excessive dilatation stresses and consequently structural damage.

Next year CRU will be celebrating its 40th Sulphur + Sulphuric Acid Conference in Barcelona, 4-6 November 2024. ■

Upgrading refractory solutions

Gouda Refractories continues to upgrade its refractory solutions for the sulphur recovery industry as well as developing new superior products for installations operating at higher temperatures due to oxygen enrichment.

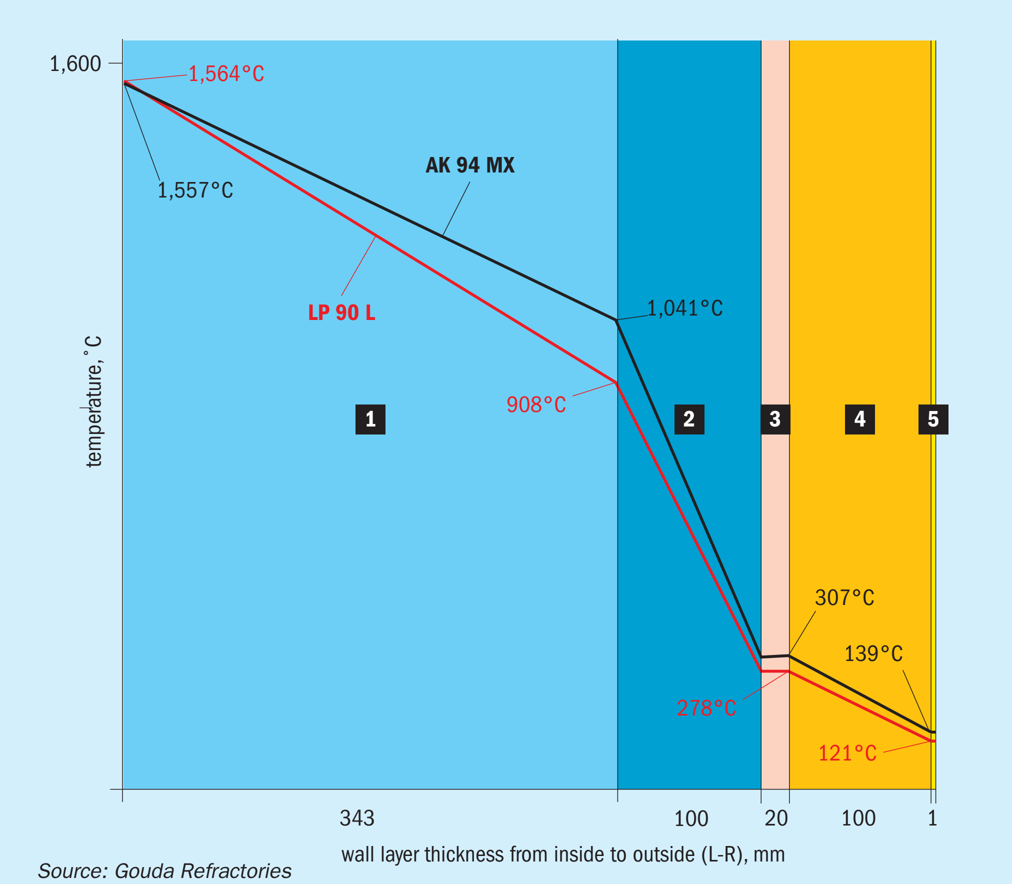
Gouda Refractories BV, a leading refractory company specialised in the lining of equipment for sulphur recovery trains worldwide, has developed a wide range of products tailored to the unique demands of these processes and actively contributes to the development of technical specifications for this equipment.

Gouda Refractories operates from two production facilities in the Netherlands, a castable plant located in Geldermalsen and a brick plant with the capability to fire dense refractory bricks at temperatures reaching up to 1,700°C situated in Gouda.

In addition to its production facilities, the Gouda office houses an engineering department and a fully equipped laboratory dedicated to quality control, failure analysis, and material development. We are proud to have a team of highly experienced refractory supervisors within our company.

As part of Gouda Refractories Group, there are installation companies located in Sweden, Belgium, and the Netherlands. Beyond the immediate group, collaborative efforts with an extensive network of global partners enables Gouda Refractories to offer comprehensive refractory solutions and serve its clients as a full-service refractory provider.

Fig 1: **Hot face material comparison: AK 94 MX vs. LP 90L**



Source: Gouda Refractories

SRU products

Gouda Refractories continually strives to develop cutting-edge refractory solutions for the sulphur recovery industry. As equipment sizes and process efficiencies evolve, Gouda Refractories has been working diligently to enhance its materials to meet clients' requirements. Notably, installations operating at higher temperatures due to oxygen enrichment demand improved stability at elevated temperatures.

To address this need, Gouda Refractories has upgraded its standard AK 94 M hot face brick to AK 94 MX, offering superior creep resistance compared to AK 94 M. This enhancement ensures higher stability under the elevated temperatures associated with oxygen-enriched environments.

Another challenge arising from the higher operating temperatures in the reaction furnaces and incinerators of SRU equipment relates to the use of dense refractory bricks, primarily composed of at least 90% alumina with corundum as the main raw material. While corundum is integral to producing highly stable bricks for these applications, it possesses limited insulating properties.

Basis for product development

When it comes to SRU equipment, maintaining the appropriate shell temperatures on the steel equipment surface is crucial to prevent dewpoint corrosion and ensure mechanical stability. In this context, the insulating properties play a pivotal role in the equipment design.

The selection of materials and qualities for the insulating layer within this equipment is somewhat limited, but it is generally observed that as the service temperature of insulating materials (be it bricks or castables) increases, their insulating capacity tends to decrease.

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

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

Additionally, when designs incorporate a castable back-up lining system, there is a challenge related to the maximum allowable tip temperature for stainless steel refractory anchors. Typically, these anchors are fabricated from AISI 304 or AISI 310 stainless steel. AISI 304 has a maximum allowable tip temperature of 760°C, while AISI 310 can go up to 850°C in accordance with specifications. If the anchor tip temperature exceeds these thresholds, it is not permissible as per the specifications, necessitating a switch to Incoloy 601. Unfortunately, adjusting the anchor thickness is not a viable solution in such cases.

The outcome of these factors is that in designs subject to higher thermal loads, achieving the desired thermal lining design within the specified parameters becomes significantly more complex.

During discussions with clients, the question arose: Could there be a better insulating hot face material without compromising on other properties? This query was passed to Gouda Refractories' in-house product development department, which embarked on the journey to create a product with improved insulating capabilities while maintaining other essential high-temperature properties. In essence, the aim was to develop a product with the same temperature resistance as existing corundum bricks and a creep resistance within the same range.

Fig. 1 and Table 1 show the results of heat transition calculations for using AK 94 MX as the hot face material compared to using LP 90 L. Notably, the interface temperature between the hot face and insulation castable changes from 1041°C to 908°C in the latter case, resulting in a 133°C reduction in anchor tip temperature.

Other developments

This innovative material has also found applications in other contexts, such as in upgrading the lining system of a large-diameter incinerator. In this case, a two-layer castable system was initially installed with a hot face that was too thin to ensure mechanical stability. To enhance the stability of the lining system, a thicker lining was required without adding excessive weight to avoid overloading the unit's foundation. Thanks to the lower weight of this high-alumina hot face material, it became feasible to design a stable refractory system by increasing thickness without significantly increasing weight.

In scenarios where there are no design criteria for minimal shell temperatures due to the absence of dewpoint corrosion risks, this brick can contribute to energy savings in high-temperature processes.

LP 90 L is just one of several options among better insulating hot face materials. Other products in the range include:

- Chamotte quality FI 45-20, with a maximum service temperature of 1,450°C and lower density compared to standard chamotte bricks.
- Andalusite-based brick AK 60 AL, suitable for temperatures up to 1,650°C.
- Bauxite brick AK 85 MP L, designed for use in alumina melting furnaces. ■

Table 1: **Hot face material comparison: AK 94 MX vs. LP 90 L**

AK 94 MX	**Inside**	**Outside**
Ambient temperature, °C	1,600	20
Surface temperature, °C	1557.1	138.6
Heat transfer coefficient, W/m²K	100	10.09*
Diameter, mm	5,000	6,128

**Calculation method ASTM C680, issue 2004, Emissivity =0.40, wind =0 m/s*

Lining characteristics

Total thickness, mm	564
Heat loss inside, W/m² (W/m)	4,290 (67,388)
Heat loss outside, W/m² (W/m)	1,197 (23,041)
Heat content total, MJ/m² (MJ/m)	1,504 (28,952)
Weight, kg/m² (kg/m)	1,223 (23,551)

Layer	Material	Width (mm)	Density (kg/m³)	Border temp. (°C)	Mean temp. (°C)	K mean (W/mK Var)
1	AK94 MX	343	3,100	1,557.1	1,287	2.674
2	Golite 160 GM	100	1,450	1,041	678	0.5049
3	Shell	20	7,850	308.6	308	49.07
4	Air flow 2.33 m/s, 72°C, 5.20Pa	100	1.0	307.1	223	1.313
5	AISI 304	1.0	7,920	138.7	139	16.7

Metal anchors 4.0/m²
Anchor length: 75 mm
Tip temperature: 864°C
TP 310 stainless steel service temperature: 850°C

LP 90 L	**Inside**	**Outside**
Ambient temperature, °C	1,600	20
Surface temperature, °C	1563.7	121.4
Heat transfer coefficient, W/m²K	100	9.522*
Diameter, mm	5,000	6,128

**Calculation method ASTM C680, issue 2004, Emissivity =0.40, wind =0 m/s*

Lining characteristics

Total thickness, mm	564
Heat loss inside, W/m² (W/m)	3,632 (57,059)
Heat loss outside, W/m² (W/m)	965.5 (18,587)
Heat content total, MJ/m² (MJ/m)	1,177 (22,655)
Weight, kg/m² (kg/m)	1,059 (20,385)

Layer	Material	Width (mm)	Density (kg/m³)	Border temp. (°C)	Mean temp. (°C)	K mean (W/mK Var)
1	LP 90 L	343	2,550	1,563.7	1,219	1.783
2	Golite 160 GM	100	1,450	908	595	0.4981
3	Shell	20	7,850	279.3	279	50.04
4	Air flow 2.33 m/s, 72°C, 5.20Pa	100	1.0	278	200	1.169
5	AISI 304	1.0	7,920	121.5	121	16.48

Metal anchors 5.0/m²
Anchor length: 75 mm
Tip temperature: 755°C
TP 310 stainless steel service temperature: 760°C

Source: Gouda Refractories

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

Innovative redesign of an economiser

Anggi Arifin Nasution and **Aldifi Putro** of PT Petrokimia Gresik detail an inventive redesign of their economiser, a critical component in sulphuric acid production, focusing on energy efficiency, decarbonisation, process optimisation, and equipment durability.

Petrokimia Gresik, a subsidiary of Pupuk Indonesia that mainly produces fertilizers, is located in Gresik, East Java and occupies an area of more than 450 hectares. It has a total production capacity of 8.9 million t/a, consisting of 5 million tonnes of fertilizer products and 3.9 million tonnes of non-fertilizer products.

Sulphuric acid is one of the most important raw materials for Petrokimia Gresik, and is used for a range of products including ZA (ammonium sulphate), SP-36 (superphosphate), and NPK Phonska (compound fertilizer). To meet the demand for sulphuric acid, Petrokimia Gresik has two sulphuric acid plants with a total capacity of 1.17 million t/a. The first plant was built in 1984, and the second plant was commissioned in June 2015.

The revamped 1,800 t/d sulphuric acid plant, Unit II, described in this article is equipped with modern technology. It uses the double contact double absorption (DCDA) process, which can achieve higher conversion efficiency and lower emission levels than the single contact single absorption (SCSA) process. The plant also has a heat recovery system that can generate steam and electricity from the waste heat of the sulphuric acid production.

The revamped sulphuric acid plant supplies the phosphoric acid plant and the NPK fertilizer plant, which are also located in the same complex. By having an integrated production system, Petrokimia Gresik can optimise its operational efficiency and reduce its production costs. This will enable Petrokimia Gresik to provide high-quality and affordable fertilizers to farmers and contribute to the national food security program.

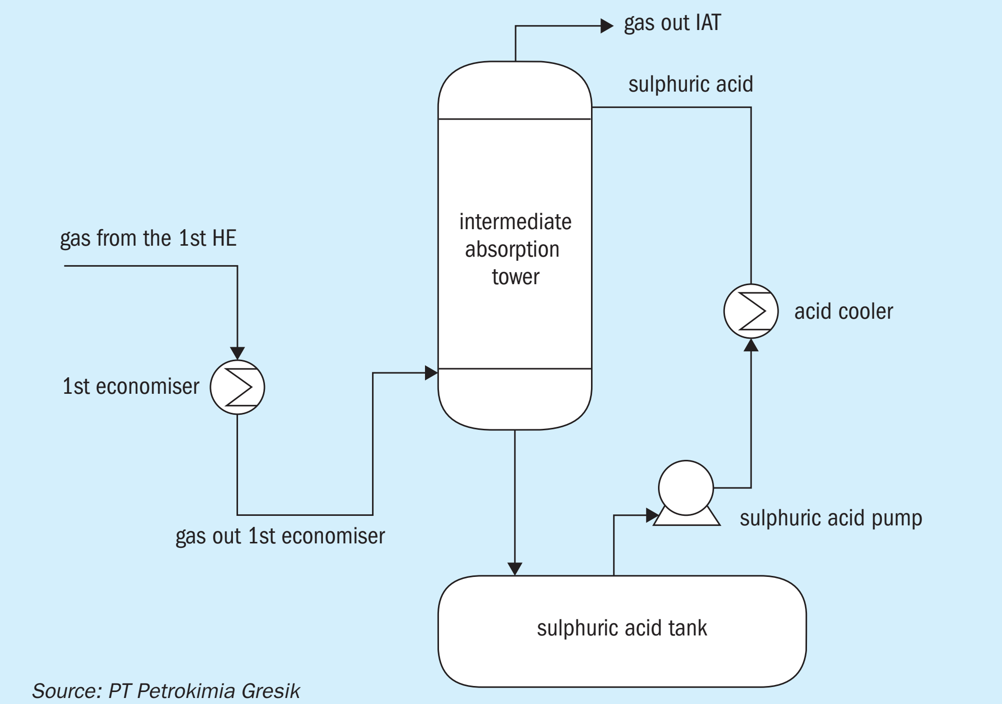
Problem description

The function of the 1st economiser (E-1203) in a sulphuric acid plant is to decrease the temperature of SO_3 gas from the 1st heat exchanger (on the shell side) before it enters the intermediate absorption tower (IAT) and increase the temperature of boiler feed water prior to its entry into the steam drum (on the tube side). Fig. 1 shows the absorption process flow diagram for Sulphuric Acid Unit II.

The original design of the 1st economiser consisted of a double-finned tube with demineralised water between the inner and outer tube that serves to keep the temperature of the outer tube, which is in contact with SO_3 gas, above the acid dew point. However, when there is damage or corrosion to the outer tube, the demineralised water reacts with SO_3 gas to form acid and condensate, which triggers faster corrosion of the inner tube.

During the July 2019 turnaround, two visual inspections and pressure tests were performed at a pressure of 60 kg/cm². A leak was found in one of the tubes (column 12 row 9), which resulted in damage to the surrounding tubes (tubes in columns 10 and 11) and corrosion on the shell side as a result of SO_3 reacting with the boiler feed water leak. The tubes in columns 10, 11, and 12 were plugged on the header side, leaving 36 tubes (12.5%) inactive out of a total of 288 tubes. Under design conditions, the SO_3 gas inlet temperature into the intermediate absorption tower is 219°C,

Fig. 1: **Absorption process flow diagram Sulphuric Acid Unit II**



Source: PT Petrokimia Gresik

and the sulphuric acid inlet temperature is 80°C. However, with up to 60 tubes of the 1st economiser plugged within four years (before the 2022 turnaround) the average SO_3 gas temperature inlet into the intermediate absorption tower was 254°C. The increase in SO_3 gas inlet temperature into the intermediate absorption tower caused splashing of the inlet gas; consequently, more mist acid was produced, which raised the demister load, impacting on the reliability and lifetime of the mist eliminator in the absorption tower.

In addition, the ideal SO_3 gas absorption temperature in the intermediate absorption tower is 80°C. In general, the higher the absorption temperature, the more difficult it is to absorb SO_3 gas; therefore, a decrease in the intermediate absorption tower inlet gas temperature will improve SO_3 gas absorption, which will increase the conversion in bed IV and reduce SO_2 gas emissions.

Subsequently, a laboratory examination was conducted to investigate the composition and underlying reason for the scaling observed on the fin tube. The results of the laboratory analysis for the scale content in the 1st economiser finned tube showed mostly SO_4 and Fe_2O_3 corrosion products (see Table 1).

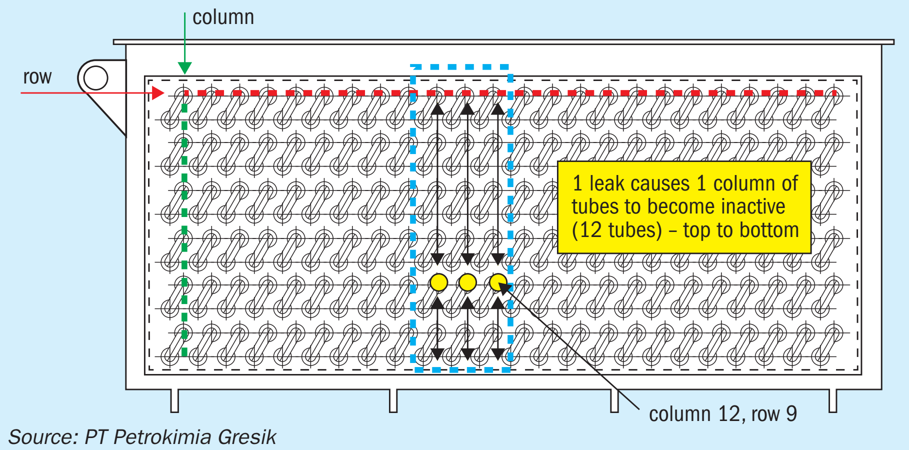
It was concluded that the scale and leakage of the tube in the 1st economiser was caused by acid formation and corrosion (see Fig. 4). Acid condensation occurs when the temperature of the tube falls below the acid dew point during shutdown and normal operation, such that the exterior of the tube corrodes and produces scale. The original design of the 1st economiser tube was a double-finned tube with demineralised water between the inner

Table 1: **Results of content analysis of 1st economiser scale**

Component	Value	Method for analysis
SO_4, %	65.49	Gravimetry
Carbon, %	2.72	Gravimetry
V_2O_5, %	0.47	AAS
SiO_2, %	0.05	Gravimetry
Al_2O_3, %	0.12	AAS
Fe_2O_3, %	27.87	AAS
pH 10%	2.41	pH meter

Source: PT Petrokimia Gresik

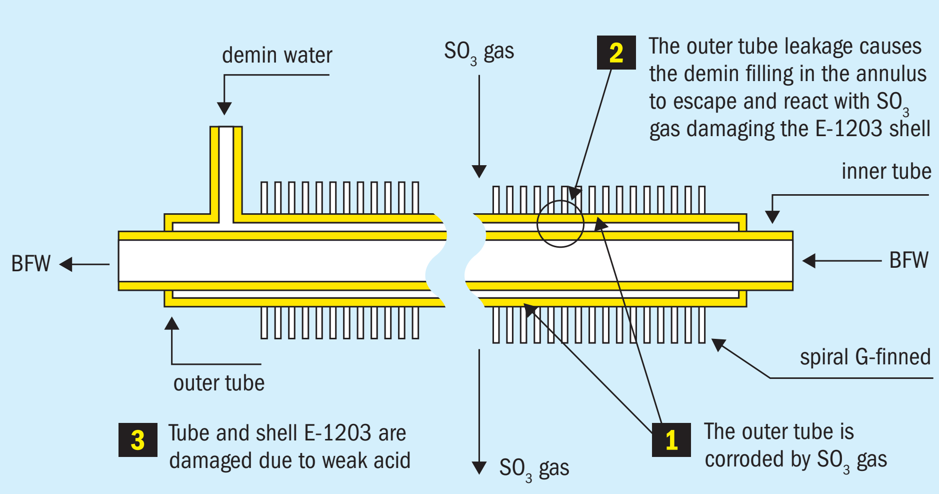
Fig. 2: **1st economiser tube detail drawing side view with leaks in 3 tubes resulting in the inactivity of 36 tubes**



Source: PT Petrokimia Gresik

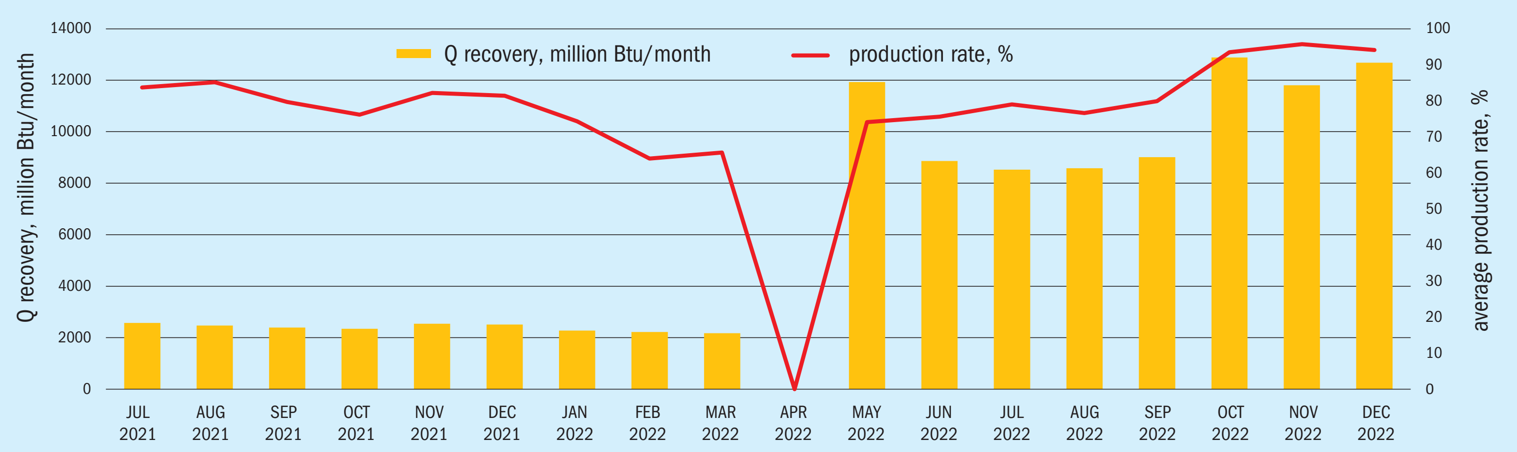
Fig. 3: Corrosion on the finned tube of the 1st economiser.

Fig. 4: **Schematic of corrosion by weak acid in the 1st economiser**



Source: PT Petrokimia Gresik

Fig. 5: **Heat recovery trend before and after the 1st economiser modification**



Source: PT Petrokimia Gresik

and outer tube (finned), which keeps the outer tube temperature above the dew point. However, the presence of demineralised water in the annulus triggers corrosion on the outer tube, resulting in damage to the inner tube, which causes a reaction between SO_3 gas and demineralised water.

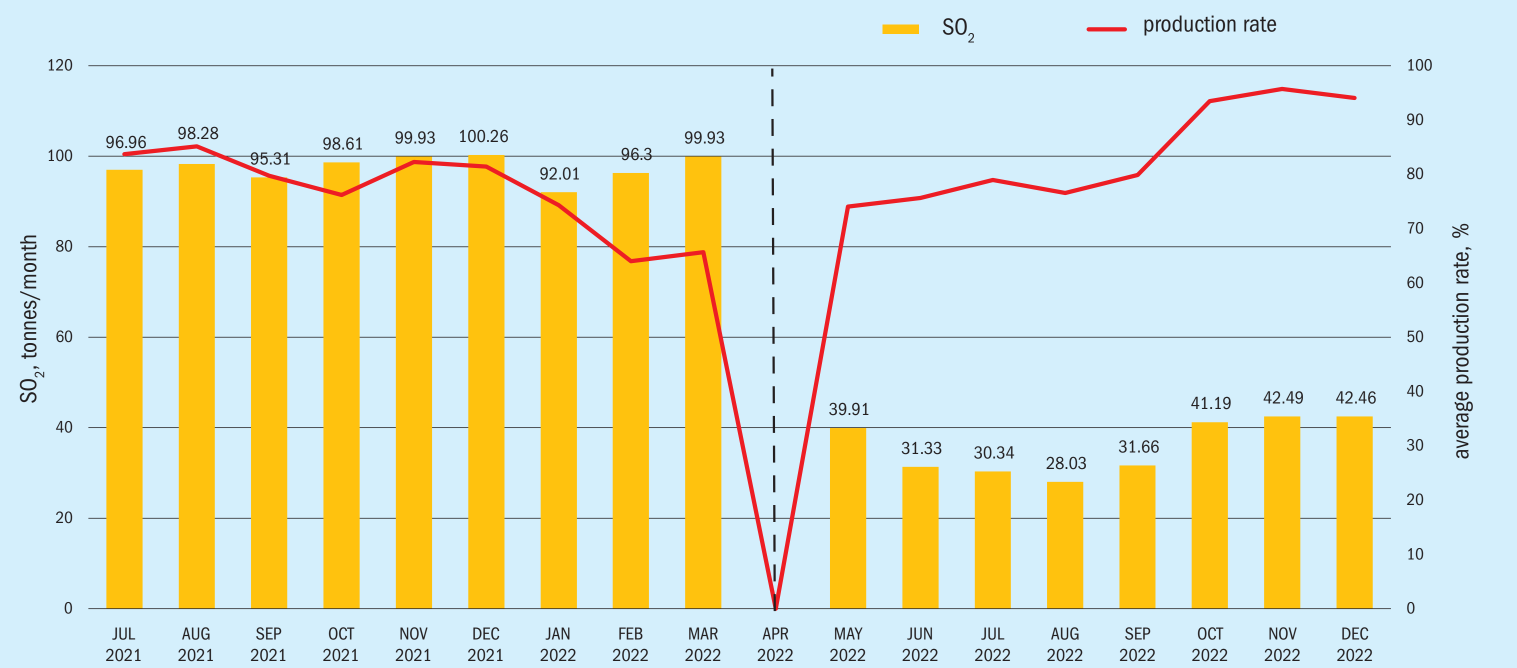
New design of sulphuric acid plant 1st economiser

Modifications have been made to the 1st economiser. It has been changed from a single compartment design, with demineralised water injection in the annulus between the inner and outer tubes, to a dual compartment design, with a single fin tube without an annulus. The modified design uses high heat transfer materials on the six top tubes and corrosion resistant materials on the six bottom tubes, considering that acid condensation tends to occur in the lower part of the economiser. The design and development of the new economiser design was carried out using ASPEN EDR (Exchanger Design and Rating) software as a technical resource for the manufacturing of the equipment. Following completion of the simulation, a new shop drawing design was conducted to determine the dimensions and installation points, as well as to simulate the load capacity of the new 1st economiser using Solidwork software. The purpose of this was to verify that the safety factor of the new equipment corresponds to pre-established standards.

Another crucial aspect involves the implementation of a HAZOP (Hazard and Operability Study), which is performed with the purpose of identifying the potential hazards and consequences associated with the installation of the new 1st economiser design. Fabrication of the economiser was conducted from January to March 2022, and the installation took place in April 2022.

The original design had a single compartment with a total of 24 columns, while the new design has a double compartment design with a total of 48 columns. In addition, the original design includes demineralised water on the annulus with a thickness of 10 mm, resulting in an inside diameter of 28 mm. In the modified design, there is no demineralised water on the annulus,

Fig. 6: **SO_2 emission trend before and after the 1st economiser modification**



Source: PT Petrokimia Gresik

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

so the inner diameter increases to 38 mm. The upper and lower compartments in the new design feature two different materials to improve heat transfer in the upper compartment while increasing material resistance in the lower compartment, which has a higher risk of acid condensation.

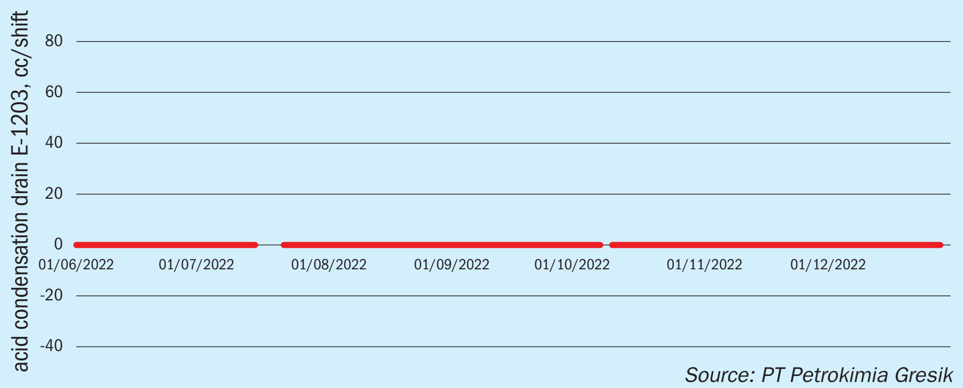
Results of improvement

The installation of the new 1st economiser was carried out during the turnaround in March–April 2022. Based on the heat recovery trend chart (Fig. 5), it is evident that following the modification of the 1st economiser, there was a notable rise in the average heat recovery. The average heat recovery increased from 2,310 million Btu/month (July 2021 to March 2022) to 8,258 million Btu/month (April 2022 to December 2022), while maintaining a similar production rate. The chart in Fig. 5 indicates that the heat recovery prior to the replacement of the 1st economiser continuously fell below the designated heat recovery. Conversely, following the replacement, the heat recovery consistently surpassed the designated heat recovery. The increase in heat recovery can be expressed through the addition of MPS (medium pressure steam). Before the replacement of the 1st economiser (July 2021 to March 2022), there were average unrecoverable steam losses of 2,031 tonnes per month, whereas, after the replacement of the 1st economiser (April to December 2022), there was an increase in steam recovery (gain) of 933 tonnes per month above the initial design.

In addition, the chart in Fig. 6 clearly shows a decrease in SO_2 emissions from the sulphuric acid plant after the modification.

The chart in Fig. 7 depicts the acid condensation drain trend for the 1st economiser from June through December 2022. As predicted in the ASPEN EDR simulation, it can be seen that acid condensation does not occur where the minimum temperature of the outer tube wall is 165.39°C, i.e. higher than the dew point for acid condensation.

Fig. 7: **Acid condensation trend after the 1st economiser modification**



Source: PT Petrokimia Gresik

The modifications and improvements to the 1st economiser design have resulted in several advantages compared to the initial design, which can be summarised as follows:

- The change in design from a double fin tube with demineralised water to a single fin tube without demineralised water eliminates the risk of a reaction between demineralised water and SO_3 when there is an outer tube leak, which can trigger faster inner tube corrosion.
- The design change to a single fin tube eliminates the risk of gaps forming between layers (e.g., carbon steel and aluminium) during the fabrication process.
- Increased reliability by changing the design from a single compartment (24 columns) to a double compartment (48 columns). In order to avoid the potential for galvanised corrosion of the U-tube joints at the boundaries of the 6th and 7th tube rows (dissimilar material), a tube header is added into the system with a flange-to-flange connection, utilising a non-metal spiral wind gasket. Additionally, nuts and bolts are applied, which have been coated with anti-corrosion paint. If there is a failure in one tube, the deactivated tube column will be reduced from 12 tubes to 6 tubes.
- Changes in the dimensions of the thickness and ID tube, namely, the initial design has a metal thickness of 10 mm (excluding 6 mm of stuffing material) to a metal thickness of 11 mm, so that the ID tube changes from the initial design of 28 mm to 38 mm. This makes the tube side pressure drop lower.
- It had the best heat exchange among simulated alternatives, with an over-design of 11.3% over the initial design. Consequently, this improvement has yielded higher steam output and high heat recovery. The gas outlet temperature could be regulated by operating the BFW valve bypass opening.
- Having a minimum outer tube wall temperature higher than the acid dew point (>165 °C) prevents acid condensation which mitigates corrosion and equipment damage, and the corrosion-resistant lower compartment material makes this design safer.

The new design has reduced the inlet gas splashing (sudden shock cooling), which has had a positive impact on the reliability and lifetime of the mist eliminator can be maintained, as well as increasing the heat recovery of the 1st economiser and conversion in bed IV of the sulphuric acid converter.

Conclusion

The economiser is a vital component in sulphuric acid production that affects the energy efficiency, environmental impact, and operational performance of the plant. Petrokimia Gresik's innovative redesign of the economiser, changed the configuration from a single compartment to a dual compartment and uses different materials and tube types for each compartment. The new design improves heat transfer, reduces corrosion, and lowers the SO_3 gas temperature at the intermediate absorption tower inlet. Using ASPEN EDR simulation and field observations at the Petrokimia Gresik plant, the outcomes demonstrate the many benefits of the new design. The results show that the redesigned economiser saves up to 8,258 million Btu/month of energy, decreases SO_2 emissions, and extends the equipment lifespan. The successful redesign of the economiser improved the sulphuric acid production process and contributes to the industry's decarbonisation objectives.

Reference

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Acknowledgement

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Seeking out energy in sulphuric acid plants

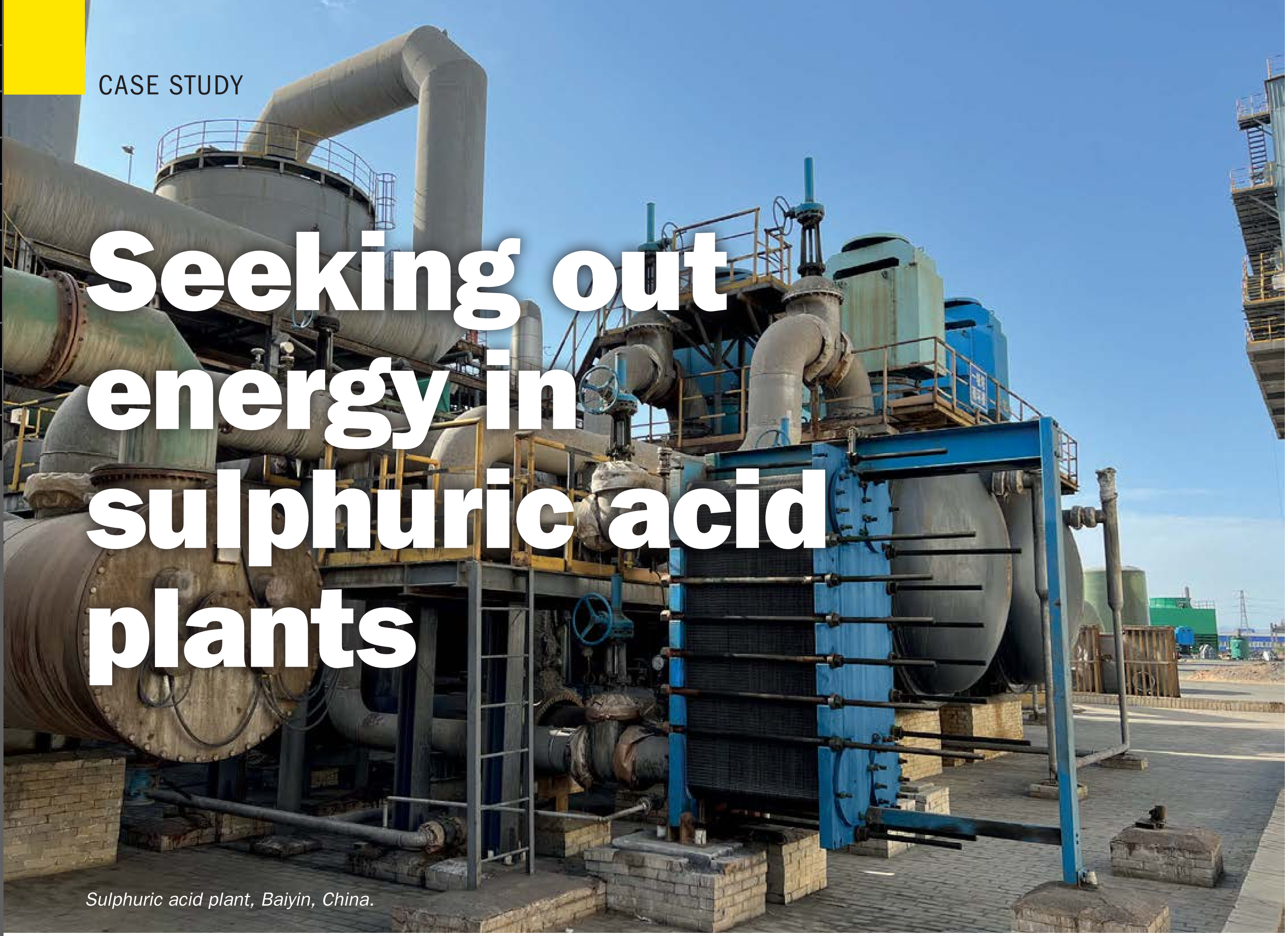

PHOTO: ALFA LAVAL

Sulphuric acid plant, Baiyin, China.

A sulphuric acid plant in Northwest China is looking to capture its low-grade heat for re-use. With the support of Alfa Laval's semi-welded plate heat exchangers and energy recovery expertise, in winter, all of the recovered low-grade heat could be put back into their system with 30% being used in production and the remaining 70% going to heating. During the summer, 14% of the energy that is no longer needed for indoor heating could be used to preheat boiler feedwater. This would enable them to significantly reduce the amount of fossil fuels used in production, without redesigning their entire factory footprint.

Baiyin city is the core area of the Greater Lanzhou Economic Zone and is a sub-centre of the Lanbai Economic Circle, which means that a lot of its infrastructure is connected to the district heating zone in northern China. With current energy demands, Baiyin city uses up its full quota of district heating within six months every year and must rely on traditional coal heating to fill the gap. But in a world where we are all trying to move away from fossil fuels, the government and enterprises are actively looking for solutions that will help them do more with less.

In the case of a sulphuric acid plant in Baiyin city, it has already taken important steps to improve energy efficiency within its production facilities. In fact, Alfa Laval has been supporting it with advanced plate heat exchanger technology that can capture excess heat for reuse in production since 2012. In a process where the plant can produce 300,000 tonnes of cathode copper and 1.1 million tonnes of sulphuric acid (calculated as 100% H_2SO_4) every year, the high and medium temperatures can easily be recovered using a boiler to generate steam for power generation and

Hunting for excess heat

Driven by the Chinese government's dual-carbon policy, metallurgical acid manufacturing enterprises have made heat recovery a standard procedure. Today, Alfa Laval has already cooperated with five smelter companies in China, using this low-temperature heat recovery technology.

But, China is not the only country looking to clean up existing infrastructure with heat reuse. Alfa Laval's Low-Temperature Heat Recovery System has been incorporated on a global scale and can be found in Sweden, Finland, the UK, Germany, India, and many other countries.

This forms part of Alfa Laval's mission to decarbonise and transform existing traditional systems with energy efficient solutions. The goal is to support customers as they reduce their energy consumption and limit the amount of carbon that enters the atmosphere each year.

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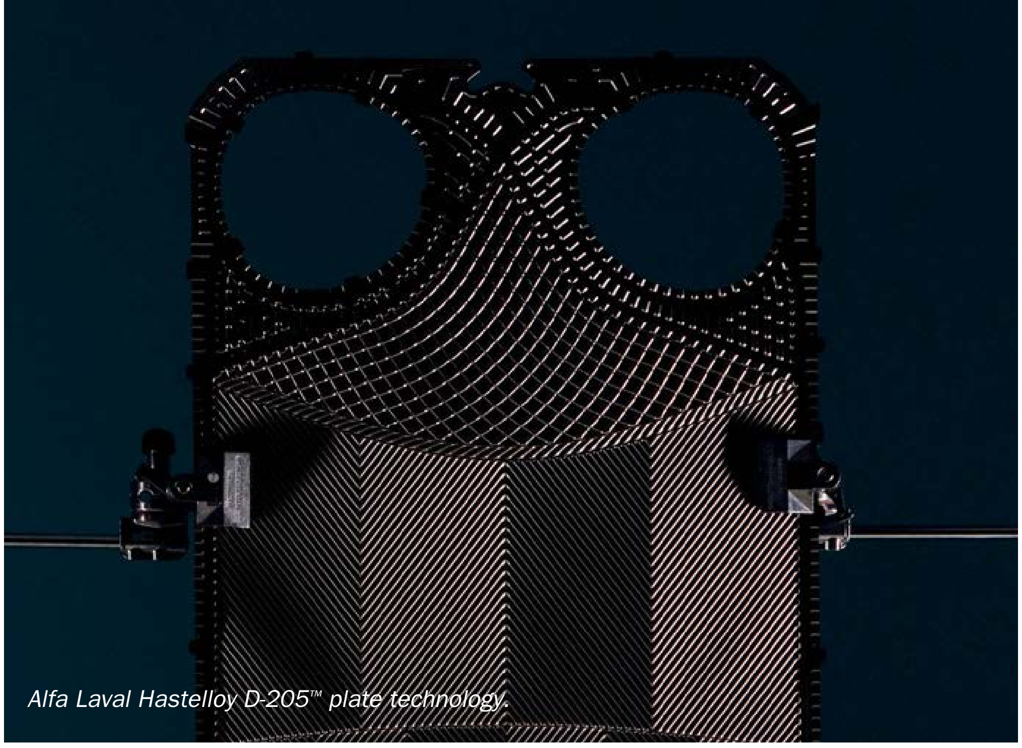


PHOTO: ALFA LAVAL

Alfa Laval Hastelloy D-205™ plate technology.

production. Despite this, the volume of excess heat that can be captured for reuse still falls short of the overall heating demands of the whole plant, especially over winter. It is therefore in urgent need of finding new ways to boost energy efficiency in its sulphuric acid production.

In traditional acid production, a large amount of low-grade heat (heat temperature below 100°C) is generated in the sulphuric acid absorption tower. But because of the extremely close temperature difference between the cold and hot sides, traditional shell-and-tube heat exchangers cannot recover this low-grade heat. In other words, this excess heat ends up discarded in cooling water instead of being put to effective use.

Capturing low-grade heat

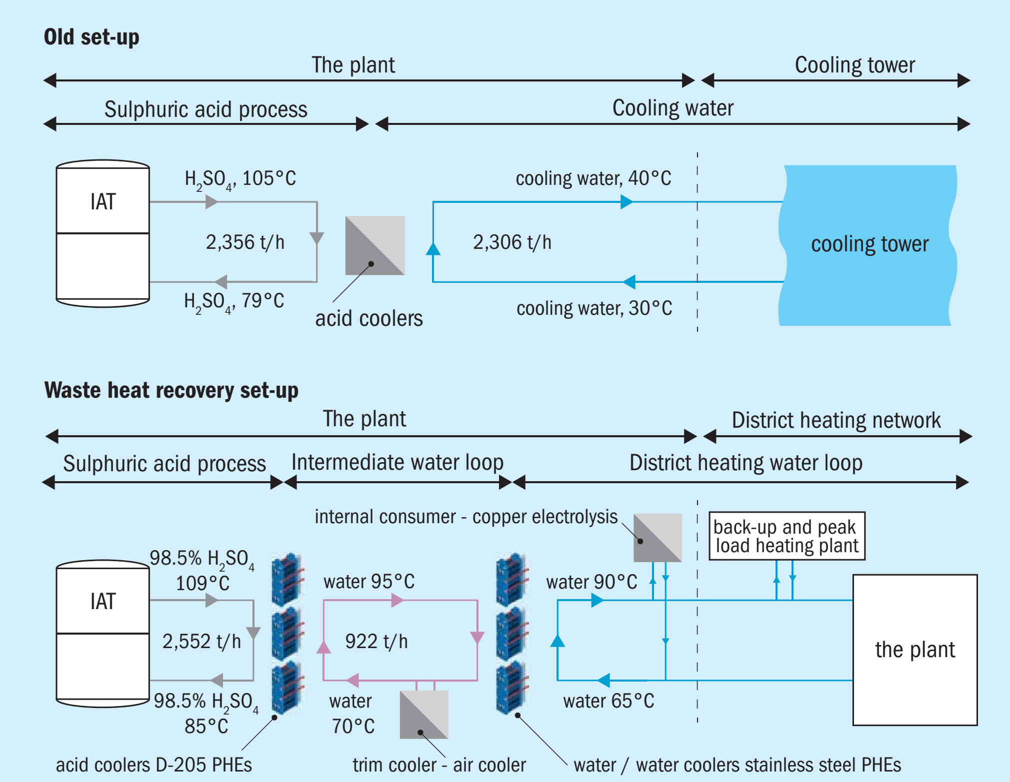
With Alfa Laval's efficient semi-welded plate heat exchanger (SW-PHE) assembly and unique Hastelloy D-205™ plate technology, the customer could have a system that recovers heat from the intermediate absorption tower cooler in the drying and adsorption section of their sulphuric acid production and generates hot water for the copper electrolyte heating in their electrolysis workshop. In addition, this excess heat generated hot water could also be used for pure water preheating, to cool their workshop, and even replace partial low-pressure steam when heating the factory in winter.

In this case, two Alfa Laval plate heat exchangers made of Hastelloy D-205™ would be the best option, as this nickel-based alloy is particularly resistant to highly concentrated sulphuric acid and elevated temperatures. With over 300 units installed worldwide over many decades, it provides a proven reliable solution for their heavy-duty fluid handling requirements.

However, the application scope of D-205 material has strict requirements. For the best possible results, it is necessary to adjust the process according to each situation. With service centres worldwide, Alfa Laval's sales and service teams coordinate, supply professional support, and follow up on all their products promptly to provide the best customer experience.

With this solution, the heat recovered from the intermediate absorption tower is 26,820 kW, which is the same as reducing 5 bar (a) low-pressure steam consumption by 45.82 t/h. This means that in winter, all the recovered heat can be reused in the system. In this case, 13.75 t/h (30%) is used in the production, while the remaining 32.07 t/h (70%) is used for heating in the heating station. During the summer, when there is no need for building heating, 14% of the 32.07 t/h is used in the pure water station and the rest is ready and available to be used where needed.

Fig 1: **Diagram showing the old set-up and the waste heat recovery set-up**



Source: Alfa Laval

Sustainable and profitable investment

Besides financial and environmental benefits, Alfa Laval's Low-Temperature Heat Recovery System also comes with the following advantages:

- a return on investment within 11 to 13 months;
- less cooling water is needed for drying and adsorption circulation in sulphuric acid production and no need to redesign the gas boiler;
- implementation is easy and won't affect any existing equipment or systems.

In Phase I of applying the Alfa Laval Low-temperature Heat Recovery System, the customer has already seen the following environmental benefits:

- they recovered 153,296 MWh of excess heat, enough to heat up 12,000 homes in Europe for a year;
- they reduced their steam consumption by 262,062 t/a
- they reduced their carbon dioxide emissions by 46,922 t/a
- they reduced their overall power consumption by 46,639 MWh per year. ■

Optimising refinery assets with fertilizer production

Honeywell UOP's nViro Hydro process provides an alternative solution to conventional hydroprocessing waste treatment utilising a sulphur recovery unit and tail gas treating unit. **Janet Ruettiger** of Honeywell UOP discusses the benefits of nViro Hydro which include improved operational efficiency, creating a new revenue stream and reduced capital outlays, operating expenses and water use.

Refineries are major long-term investments that operate over many years spanning decades. As technology, consumer needs, product values, and environmental regulations evolve, refineries adapt. In today's economy and environment, refiners must account for not only every dollar spent, but also consider whether they are making the best use of every molecule at their disposal.

Hydroprocessing complexes are a critical component of almost any refinery. Hydrotreating reactions remove sulphur and nitrogen contaminants from hydrocarbon feedstocks to produce clean fuels and petrochemical feedstocks, and hydrocracking reactions break long-chain hydrocarbons into smaller chains to increase the yield of valuable products. Flexibility to increase feed throughput and/or feed quality in their hydroprocessing unit(s) can help refiners maintain profitability, meet changing production targets, manage variation in feedstock supply and/or offset the shutdown of obsolete assets.

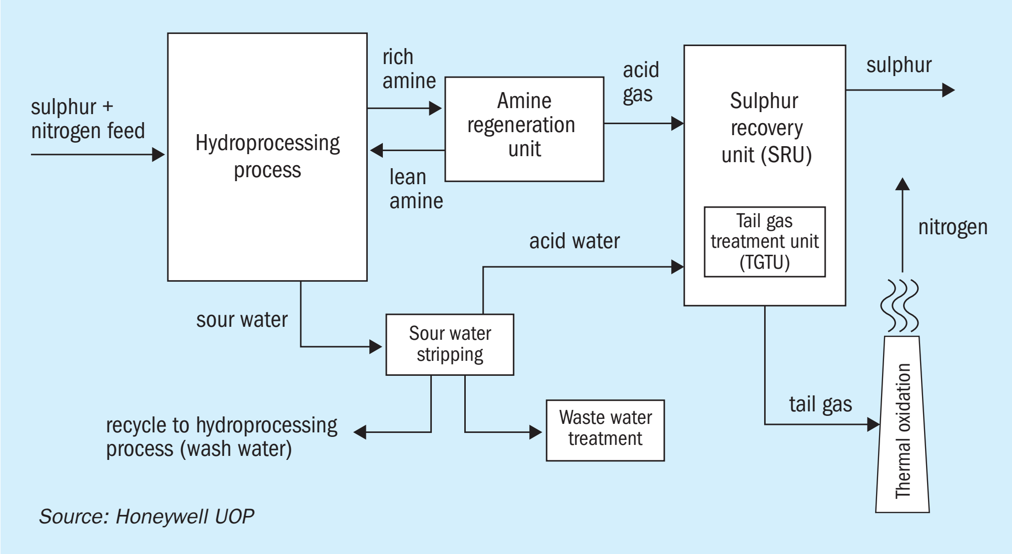
If constraints are met in the current hydroprocessing design, incremental advances in technology (i.e., higher activity catalyst, slimmer reactor internals, etc.) are typically implemented during turnarounds to optimise and relieve constraints. However, the combination of throughput increases, feedstock changes, and tightening emission specifications can create an effluent treatment bottleneck in refineries, putting a strain on existing sulphur recovery and wastewater treatment sections.

The proprietary UOP nViro™ Hydro solution provides an alternate waste management solution for green-field or brown-field hydroprocessing complexes. Compared to the conventional treatment processes, nViro Hydro can improve operational efficiency, create a new revenue stream, and reduce capital outlays, and operating expenses[1].

Conventional sulphur recovery scheme

A simplified conventional scheme for hydroprocessing waste treatment (Fig. 1) utilises a sulphur recovery unit (SRU) and a tail gas treating unit (TGTU) to convert hydrogen sulphide (H_2S) to elemental sulphur. From these processes the elemental sulphur is collected and can be sold as a commodity. In the conventional scheme, the ammonia (NH_3) waste travels with the H_2S through the SRU and is eventually released into the atmosphere after being converted into N_2 and/or NOx. Not only is the value of the NH_3 not captured in this scheme, but the NH_3 takes up useful capacity in the SRU, limiting optimisation. While the conventional scheme mentioned earlier includes tail gas treatment, the requirement for tail gas treatment varies regionally based on emission regulations. Some refiners may operate without tail gas treatment, while

Fig 1: **The traditional flow scheme incorporates a sulphur recovery unit and tail gas treatment unit. This is a high capital cost scheme to produce a low value sulphur product.**



Source: Honeywell UOP

others may be facing mandatory capital expenditures to comply with regulations and maintain operation.

nViro Hydro: Sulphur (and nitrogen) recovery solution

The UOP nViro Hydro solution (Fig. 2), is a proprietary process for the treatment of acid gas and sour water from a hydroprocessing complex and offers an alternative approach to conventional sulphur recovery. nViro Hydro can be implemented in new complexes at a lower capital cost than the conventional scheme (with TGTU)[1], or it can be added to an existing complex (utilising the existing SRU to limit capex) as a tool to relieve optimisation limiting constraints or as an alternative to the addition of a TGTU to meet emission specifications.

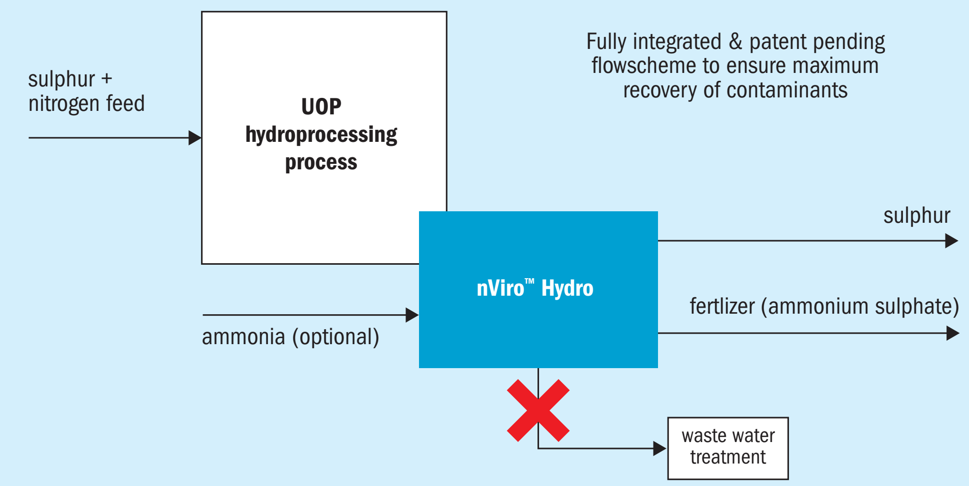
In the nViro Hydro process, the main waste products, hydrogen sulphide and ammonia, are upgraded into a combination of both elemental sulphur and ammonium sulphate ($(NH_4)_2SO_4$), a chemical that is commonly blended as an ingredient in multi-nutrient NPKS fertilizer blends.

Utilisation of waste ammonia to produce ammonium sulphate with the nViro Hydro process allows for a number of economic, operational and environmental benefits beyond what is capable with a conventional sulphur recovery scheme[1].

Economic and environmental value of ammonia

Ammonia is a key ingredient in the production of ammonium sulphate and other ammonia-based fertilizers. Utilising waste ammonia optimises the treatment process from both an economic and environmental perspective. Ammonia is both economically valuable ($270-$354/t in July 2023 for grey ammonia)[2] and CO_2 intensive to produce. The most predominant production method of ammonia, the Haber Bosch process, produces between 2.3 and 5.2 tonne CO_2 per equivalent tonne of NH_3 depending on the region of production and efficiency[3]. Less CO_2 intensive ammonia production methods, such as blue and green ammonia, are available, but come at a premium ($299-384/t and $750-$799/t for blue and green ammonia in July 2023)[2]. Leveraging of waste ammonia in the nViro Hydro solution gives refiners an advantage relative to other ammonium sulphate production methods.

Fig 2: The nViro™ Hydro flow scheme is fully integrated to ensure maximum recovery of contaminants



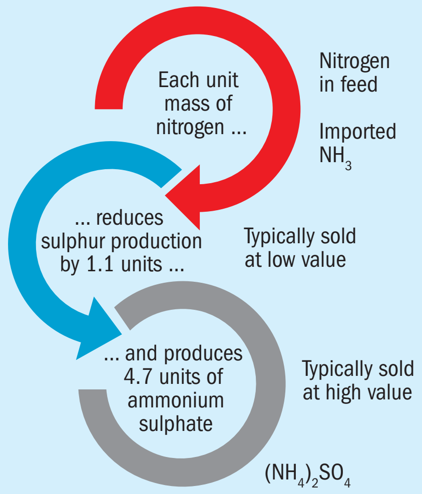
Source: Honeywell UOP

Ammonium sulphate as a profit increasing byproduct

The value of ammonium sulphate production from nViro Hydro compared to the conventional solution depends on the relative pricing of ammonium sulphate versus sulphur. The chemistry of ammonium sulphate production gives nViro Hydro an economic advantage over sulphur production, multiplying the yield of ammonium sulphate by nearly 5 times the amount of sulphur that is converted on a mass basis due to the mass of the ammonia and oxygen in the ammonium sulphate molecule[4].

This results in an increase in total product value from nViro Hydro relative to conventional sulphur recovery, with contributions from both increased yield of byproducts and the fact that ammonium sulphate often carries a higher value than elemental sulphur (Fig. 3).

Fig 3: Ammonium sulphate production vs. elemental sulphur production



Source: Honeywell UOP

About 50% of global elemental sulphur recovered ends up in fertilizers anyway, including phosphates and ammonium sulphate, but via a more arduous and less efficient route with multiple conversion processes[5].

The ammonium sulphate produced by the nViro Hydro process can be sold directly as a powdered material, or if desired an additional compaction step can be added to the nViro Hydro process which may increase the value of the ammonium sulphate and/or make the product more marketable.

The global demand for ammonium sulphate is expected to grow at a compounded rate of ~2.6% per year through 2027[6].

Because feedstocks that are processed in hydroprocessing units, such as vacuum gasoils (VGO), diesels, deasphalted oils (DA)), coker gasoils (CGO), etc. tend to contain orders of magnitude higher feed sulphur than nitrogen, the yield of ammonium sulphate is set by ammonia availability, and elemental sulphur is produced with the remaining H_2S in the sulphur recovery section which remains a significant part of the design[1]. In addition to waste ammonia, additional ammonia can be imported to increase ammonium sulphate production, depending on customer objectives.

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Debottlenecking existing SRUs

Fertilizer production aside, an nViro Hydro retrofit can be a powerful tool to help refiners free up capacity in their existing assets to allow for better optimisation of their hydroprocessing complex. Refiners facing constraints in their SRU can add nViro Hydro to their complex to facilitate throughput increases with the potential to multiply the profits from their hydroprocessing units. Likewise, feedstock flexibility will increase with additional sulphur recovery capacity. In a hydroprocessing unit, the nViro Hydro system is added to the existing equipment to minimise capital expenditure, and ammonia import is an option that can be explored to increase the range of optimisation or debottlenecking of the SRU.

Another feature of the nViro Hydro system which sets it apart from the conventional sulphur recovery scheme is that it eliminates the requirement for wastewater treatment from the hydroprocessing waste treatment section[1]. This can help refiners with constraints around existing wastewater treatment capacity.

Refiners who could otherwise increase their hydroprocessing throughput, if it weren't for a constraint in their sulphur recovery section, can use nViro Hydro to increase by-product value (which gives a positive NPV and typical payback period of 1-2 years[1]) and increase production of fuels/petrochemicals.

For an even larger impact, nViro Hydro can also be implemented as part of a larger scope project with UOP's hydroprocessing experts to further optimise feed and throughput in the hydroprocessing unit through adjustments like catalyst, reactor internals and cycle length.

Fig 4: **Case study A**

Key benefits of nViro Hydro relative to conventional flow scheme with SRU + TGTU

Case A | New unit | 50 kbspd | 2.6 wt% S | 1,300ppm N | Europe

Decreased capex	-$37 million
Decreased opex Less fuel usage and water usage	-$37 million per year
Upgrade sulphur to fertilizer	-$37 million per year
Improvement in total product NPV_{20}	-$37 million

*Based on example technoeconomic evaluation utilising regional prices sets for products from IHS Markit 2021 for Western Europe.
**Does not include regional economic incentives for CO_2 reduction
***Based on sulphur price of $80/tonne and ammonium sulphate price of $220/tonne

Source: Honeywell UOP

Fig 5: **Case study B**

Key benefits of nViro Hydro relative to conventional flow scheme with SRU + TGTU

Case B | Revamp | 50-60 kbspd | 2.6 wt% S | 1,300ppm N | Europe

Increased throughput	20% per year
Decreased opex Less fuel usage and water usage	-$3.0 million per year
Upgrade sulphur to fertilizer	+$11 million per year
Improvement in total product NPV_{20}	+$40 million

*Based on example technoeconomic evaluation utilising regional prices sets for products from IHS Markit 2021 for Western Europe.
**Does not include regional economic incentives for CO_2 reduction
***Based on sulphur price of $80/tonne and ammonium sulphate price of $220/tonne

Source: Honeywell UOP

Reduced operating expenses and CO_2 footprint

In addition to the aforementioned applications of nViro Hydro, it can also be applied as a pathway to reduce utility consumption, opex and CO_2 emissions without an adjustment in the production of fuels or petrochemicals from the complex[7]. nViro Hydro reduces the load on the existing SRU, waste water treatment system and eliminates the need for the TGTU. nViro Hydro is also optimised to maximise energy recovery, benefitting both operating expenses from utilities and scope 2 CO_2 emissions[7]. This will be dependent on each customer's existing configuration and goals.

Table 1: **Increased product value from nViro Hydro at different sulphur price levels (Case C)**

	Flow (thousand t/a)	**Low value sulphur** ($80/t) $ million/year	**High value sulphur** ($460/t) $ million/year
Base product value of elemental sulphur	104	8.3	47.8
Decreased product value of sulphur	-4.6	-0.6	-3.5
Increased product value from ammonium sulphate	+31.3	+10.6	+10.6
Additional product value from nViro Hydro		+10.0	+7.1

Source: Honeywell UOP

Case study A: New hydrocracking complex

In this case study an oil and gas company is building a new hydrocracking unit at one of its existing refineries. The unit is designed to process up to 50,000 barrels of vacuum gasoil (VGO) per stream day. The VGO has a sulphur content of 2.6% and a nitrogen content of 1,300 parts per million by weight. Building the system with nViro Hydro instead of a conventional waste handling system will deliver significant financial benefits[8], which are summarised in (Fig. 4).

Case study B: Existing complex

An oil and gas company hydrocracking unit is currently operating the same feed as case A at the design capacity of 50,000 barrels of VGO per stream day, using a conventional flue-gas treatment scheme. The company wants to use new-generation catalysts with higher activity to increase hydrocracking unit throughput in the next cycle. However, they are constrained by their sulphur recovery unit.

By implementing an nViro Hydro revamp solution on their existing unit, at a cost of $29 million, the company, which was limited in throughput by their SRU will be able to increase hydrocracking throughput by 20% (with some ammonia import) and realise multiple financial and operational benefits[9] summarised in (Fig. 5).

Case study C: Sulphur pricing sensitivity

Because the yield of ammonium sulphate is so favourable relative to elemental sulphur production, even in circumstances where the sulphur value becomes very high, product value is still increased with nViro Hydro (see Table 1).

Value creation through problem solving

In order to make the most profit from fertilizer production, logically sites with a significant amount of waste ammonia at locations with strong ammonium sulphate markets are preferred.

However, looking at the bigger picture, the best use case of nViro Hydro is for the refiner to use it as a tool to solve a problem, the impact of which may cascade outside the scope of waste treatment:

- to remove a sulphur recovery constraint to increase feed throughput and fuel yield[9];
- to comply with new emission specifications without a TGTU (with positive NPV)[1];
- to reduce Scope 2 CO_2 emissions without reducing fuel yield (with positive NPV)[7];
- to reduce demand on wastewater treatment (to enable plant optimisation)[1];
- to help meet regional fertilizer demand/ reduce reliance on imports.

References

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4. Due to stoichiometry, one sulphur molecule with (MW=32.065) will convert to one ammonium sulphate molecule with (MW =132.14)
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8. Ref. 1, scaled internally, for Unicracking unit at 50,000 bpsd capacity. Product pricing based on IHS Markit AS price (220 $/t) and S price (80 $/t).
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Next generation sulphur plant analysers

As plants move towards full unit control, **Jochen Geiger** of Ametek Process Instruments provides an overview of how the latest sulphur plant analysers are providing greater insight into sulphur plant operations.

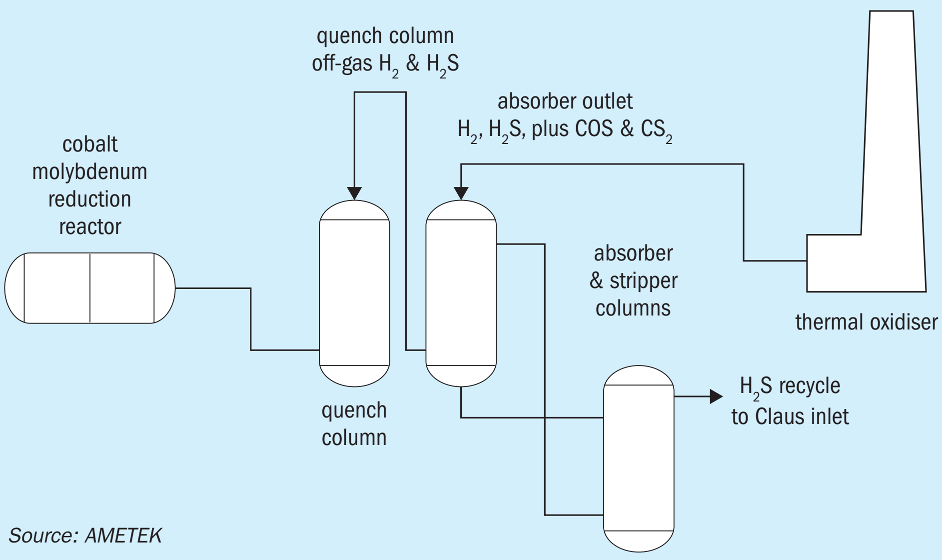
When looking at process optimisation, besides process control itself, it is important to consider new developments. To improve process yield we may look for new equipment and consider different process control mechanisms, but what about mitigating upset conditions? The results from installed process instrumentation is often questioned whenever there are any unexpected process conditions. Previous publications have discussed this in detail, but what can we learn from those discussions?

First, it is important to analyse the root cause for the lack of trust (if it exists) in the results shown by the process analytical equipment, which can be misinterpreted. As with all electronic equipment, the development of new features is happening at a rapid rate. For example, with regard to process analysers, improvements in data transmission have been introduced in recent years.

In the past, with the exception of process gas chromatographs, process analysers were mostly designed to analyse one component. Today, however, a wide range of multi component instruments are available, but despite being known to the instrumentation department, the process control team often sticks to its usual program.

For example, one very common application in the sulphur recovery industry is the measurement of excess hydrogen at the quench tower outlet in an amine-based tail gas treatment unit (TGTU). A basic flowsheet of a TGTU is shown in Fig. 1.

Fig. 1: **Basic flow sheet of a TGTU**



Source: AMETEK

In the first SCOT units (Shell Claus Off Gas Treatment units) there was a single component measurement for hydrogen. Today, however, in several installations Ametek has found two measurement locations in a TGTU process. Besides the quench tower outlet, there is a sample point at the amine absorber outlet, where hydrogen sulphide (H_2S) can be measured to ensure that the concentration does not exceed the limits. Looking into the process chemistry shows that at both sample points other components can be of interest as well. For example, at the quench outlet, besides the hydrogen measurement, H_2S is also a component of interest. Downstream of the absorber outlet additional components to consider are hydrogen for redundancy, plus carbonyl sulphide (COS) and carbon disulphide (CS_2). Both sulphur components will provide information about the reaction of the cobalt-molybdenum catalyst in the reactor.

Nowadays, modern process analysers are able to make these measurements simultaneously with one instrument. This is essential to achieve further process optimisation. Gaining more information about the process, if used correctly, will help to better understand "upset conditions" which in turn will help to mitigate them in the future.

The instruments need to be easy to operate, simple to connect with the process and provide readings to the process control team in a timely and reliable manner.

Process gas chromatographs (PGC) are still widely used today for applications which require multicomponent analysis. However, PGCs require a lot of maintenance and are considered as "complex" plus, depending on the application, require several utilities.

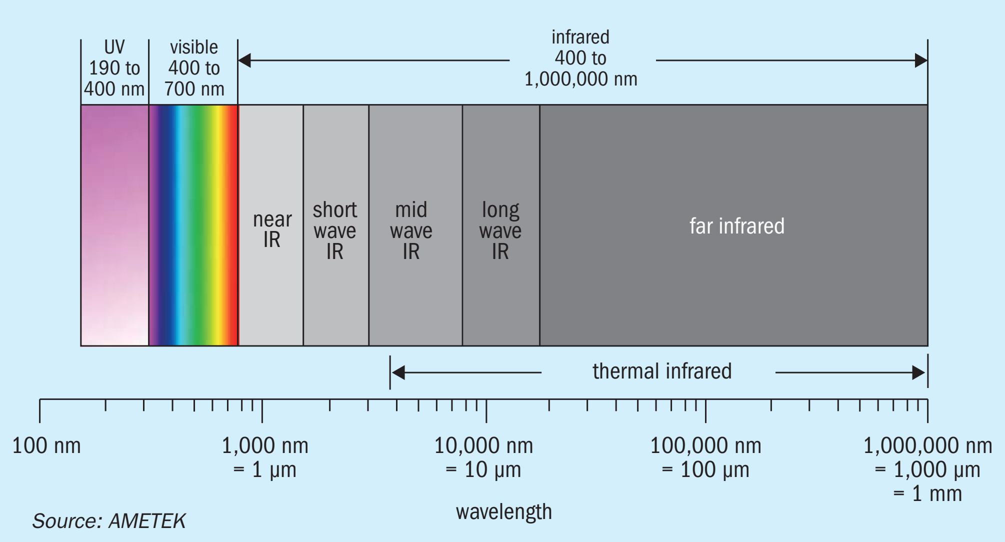
Alternatives are available and now this measurement tool has been brought to a modern process analyser platform. Most sulphur reaction gases are strongly absorbed in the ultraviolet area of the light spectra (Fig. 2).

What makes analysis in the UV range of the absorbance spectra so unique is that no water and no hydrocarbons are absorbed there, making sample preparation simpler and safer. There is no need for a chiller or any other method of sample preparation. Water is a strong absorber all over the infrared spectra and the same applies for the hydrocarbons. For the TGTU, one remaining concern is the measurement of hydrogen, which does not absorb in the usable infrared or ultraviolet spectra. For this reason, a multi sensor technology is used. The new process analyser platform can incorporate different measurement technologies: ultraviolet for sulphur species, infrared for hydrocarbons plus CO/CO_2 and a thermal conductivity detector for the hydrogen.

Fig. 3 shows an instrument that incorporates all of these measurements. The modular design makes customised solutions possible. The electronics are located on the left with the sample measurement enclosure on the right and the sample handling part below. All components are easily accessible.

With decades of experience measuring sulphur components in gas, gas processing and refinery process streams, Ametek focused on developing the 993X with features requested from Model 93X end users and maintenance teams. Standard features include a 7-inch, colour touch screen display, Modbus TCP and Modbus RTU support, at least four isolated and self-powered analogue outputs, and a longer lamp life.

Fig. 2: **Light spectrum wavelengths**



Source: AMETEK

With its rugged design the instrument can be use in a wide range of ambient air temperatures from -20°C to 50°C (-4°F to 122°F), which leads to a lower installation cost.

An Ethernet port is a new standard on modern process instruments, allowing remote service diagnostics, which helps to reduce onsite service activities.

This latest model now completes the series of sulphur plant control analysers.

When selecting or installing a process analyser it is important to consider how to get a representative sample from the process to the instrument as well as sample disposal arrangements. Other important considerations with regard to any process gas analysis in sulphur recovery plants is whether the instrument is safe to work with and whether the overall design includes enough flexibility to allow the instrument to work over a wide range of operating conditions. A fully functioning instrument is required during upset conditions.

The automated process control has isolated and self-power analogue outputs which enables monitoring of relevant components within the required control range.

For monitoring "upset conditions" there are digital outputs such as MODBUS. All process analysers have the capability to monitor "over range" readings by a factor of two to three outside the calibrated range. This is important to keep an eye on the process during upset conditions.

For instrument reliability an Ethernet connection is important to allow the instrument to be checked remotely.

PHOTO: AMETEK

Fig. 3 The completely redesigned 993X analyser delivers a more versatile and intuitive measurement solution to end users.

PHOTO: AMETEK

Sulphur plant control analysers.

Instrument implementation

Today, modern SRUs can range in capacity from tens to thousands of tonnes per day of sulphur production. Over the decades, significant improvements have been made to the overall recovery efficiency. While it was sufficient to operate at 80 to 85% in the 1970s and between 95 and 99% in the 1990s, today it has become standard to operate at recovery efficiency rates of 99.9 +%.

Considering that we, more or less, rely on the same chemistry that has been used for over 90 years, with the exception of tail gas clean up units, such efficiency improvements were only possible by using reliable process instrumentation.

It is important to understand the potential impact on the process control scheme for each of the measurements provided by the instrument installed. What are the alternative measurement scenarios, what would be "nice to have" and what is actually required to achieve the emissions targets from the sulphur recovery unit? Keeping in mind that too much information potentially leads to confusion.

The challenges are:

- understanding the environmental impact for each instrument;
- finding the best instrument combination to gain the best improvement;
- keeping the instruments in operating condition;
- mitigating upset conditions by understanding "unexpected" instrument behaviour.

Instruments are required to react fast to process changes, work reliably over the time required and maintain the highest possible safety standards.

Another topic of discussion these days is process optimisation to keep emissions at a low level plus reducing energy consumption. A common sulphur plant process configuration consists of a modified Claus process with a downstream amine-based tail gas treatment process to provide an overall sulphur recovery efficiency of 99.98+% and assuring low sulphur dioxide (SO_2) emissions. Instrumentation can be installed to make further improvements. For example, in the modified Claus process the existing air demand analyser can be used with a feed gas control system based on a feed gas analyser system. Depending on the SRU train setup this type of control scheme will help to optimise the overall sulphur recovery performance. In plants with an amine-based tail gas treating unit it will help to reduce upset conditions. In an extreme situation the information provided by the feed gas system can help to protect the amine absorber from SO_2 breakthrough, keeping in mind that the TGTU will not be significantly impacted when the hydrocarbons are appearing. In fact, an increase of hydrocarbons in the feed gas will lead to an air deficiency situation and the H_2S concentration in the tail gas will increase. So, less conversion of other sulphur compounds to H_2S means less work for the TGTU. Unfortunately, hydrocarbons can disappear as fast as they appear. No-one is able to forecast when a process upset starts or when it ends. As an upset is identified, the control system will manage the air flow to the reaction furnace, getting everything to the required set points for optimal operation. However, when the upset ends, the hydrocarbons disappear, leaving a situation where too much air is supplied to the reactor furnace and the SO_2 concentration in the tail gas will be too high. How high, nobody can predict! So now the system and operators are asking themselves: "Do I have enough hydrogen available to hydrolyse the SO_2 into H_2S? "

This leads to the question of how to ensure that the plant control is based on correct information? In many other cases it is standard for important components to be designed in a redundant manner. Unfortunately, this has not been the case for operating TGTUs. There are units with a single excess hydrogen measurement at the quench tower outlet. Now with the appearance of multi sensor process instruments it is becoming easier to "convince" operators to consider redundancy for the hydrogen measurement.

The new standard for TGTU instrumentation is to measure hydrogen plus H_2S at the quench tower outlet as well as hydrogen plus COS and CS_2 at the amine absorber outlet.

Conclusion

Modern process instrumentation has the potential to help reduce the emissions from a sulphur recovery unit. The initial investment is not negligible, but it is a highly challenging application with regard to measurement reliability and safety – the SRU has the most toxic gas mixtures of the entire refinery. The average lifetime of an instrument in a sulphur plant is 15 to 20 years.

Knowledge, understanding and awareness training are essential to maintain the instruments, and without the instruments the emission targets are not achievable. It is important that different technical disciplines work together, starting at the design phase of the processing unit. Misunderstandings about piping can result in unsafe installations. Choosing the "wrong" instrument may result in not achieving the best possible process performance. ■

Sulphur plant revamps to meet future challenges

M. Rameshni and **S. Santo** of Rameshni & Associates Technology & Engineering (RATE USA) discuss some of the many solutions available to revamp sulphur plants to meet stricter environmental regulations with regard to SO_2 and CO_2 emissions. RATE technologies for the ultimate goal of achieving near zero SO_2 emissions and World Bank requirements are also illustrated.

The revamp of existing sulphur plants to meet future challenges can be categorised into several scenarios including CO_2 removal, SO_2 emission reduction, and impacts of IMO with regard to both CO_2 and SO_2.

CO_2 recovery from facilities, including sulphur plants, is one of the hot topics that the oil and gas industry is focussing on to reduce the emission of greenhouse gases such as CO_2 from the atmosphere. A number of different separation technologies can be employed for post-combustion capture or pre-combustion capture. They include:

- adsorption;
- physical absorption;
- chemical absorption;
- cryogenics separation
- membranes:
- RATE combination of membrane and CO_2 liquefaction.

SO_2 emission reduction requirements vary around the world. The United States and Europe are required to meet SO_2 emission targets ranging from 250 ppmv to less than 50 ppmv depending on the local regulations. The World Bank has also set an SO_2 emission requirement of less than 50 ppmv for funding new investments which translates to a recovery of 99.99%. A three-stage Claus unit can meet a sulphur recovery rate of 95-97%. Some facilities are looking for a robust, simple and reliable solution to increase the sulphur recovery rate with minimum investment, minimum shutdown period, minimum or no training and no pre-investment for recovery beyond 97% or 99.5%. A number of solutions are discussed in this article:

- Changing the typical Claus catalysts to more advanced formulated catalysts could increase the sulphur recovery from 97% up to 99.5% and will meet such regulations with minimum modifications to the existing units. RATE offers two catalysts SMAX-100 and SMAXB-100 for selective oxidation of H_2S to sulphur and selective reduction of SO_2 to sulphur.
- Adding a tail gas treating unit (TGTU) with an amine section to a two- or three-stage conventional Claus unit can reduce SO_2 emissions to between 100 ppmv and 250 ppmv depending on the amine solvent selection.
- Adding RATE's TG-MAX technology: In the TGTU after the hydrogenation reactor, a hydrolysis reactor is added to maximise the hydrolysis of COS and CS_2 and to minimise the SO_2 emission. The vent gases from the sulphur pit, degassing and the sulphur storage tank are collected and recycled back to the reaction furnace of the SRU.
- Adding RATE's SETR process to increase sulphur recovery beyond 99.5% without the need for conventional tail gas treating: SETR is located after the incinerator and before the stack and can be applied after any type of TGTU.
- A caustic scrubber can be added after the thermal incineration and before the stack. This scheme is widely used and is an alternative scheme to SETR.
- Adding a sulphuric acid plant after the sulphur recovery unit will reduce SO_2 emissions and produce sulphuric acid which has many uses within a facility.
- Adding RATE's Catalytic Tail Gas Incineration (CTI) or Catalytic Tail Gas Incineration MAX (CTI-MAX). The SO_2 can be treated by using a caustic scrubber, or by using ammonia to produce ammonium sulphate as a useful product.

Meeting IMO regulations using different levels of oxygen enrichment: IMO 2020 mandates a maximum sulphur content of 0.5% in marine fuels globally. The additional sulphur compounds shall be removed from the upstream units before the sulphur recovery unit to meet the new regulations. In addition, for lean acid gas some level of oxygen enrichment could help to improve the sulphur recovery.

CO_2 recovery options[1]

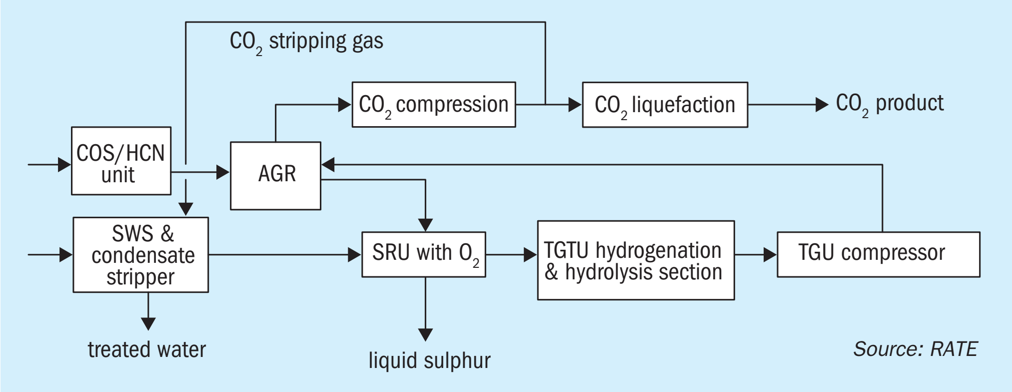
Decarbonisation options including pre-post and post combustion CO_2 removal in SRUs were discussed previously in *Sulphur no. 404*. The required energy for CO_2 removal is very important where CO_2 is produced to remove the CO_2. It is crucial to carefully evaluate the CO_2 removal case by case and to select the most economical option.

RATE has filed a patent application with the US Patent Office that covers the combination of CO_2 recovery and hydrogen generation in SRUs (not yet published).

Recently, RATE has been working on a project for CO_2 recovery and SO_2 emission control in Europe. Fig. 1 provides an example showing how CO_2 and SO_2 emissions can be reduced. The main RATE technologies employed are as follows:

- CO_2 liquefaction unit – using CO_2 liquefaction instead of an amine type unit is very economical and the required energy is significantly reduced;
- Two-stage sour water stripper (with H_2S absorber);
- COS hydrolysis reactor in the tail gas unit (an additional reactor after hydrogenation reactor);
- SRU oxygen enrichment.

Fig. 1: **Post combustion CO_2 removal from SRUs and low SO_2 emission**



Source: RATE

SO_2 emission reduction options

Controlling SO_2 emissions is one of the critical challenges that many countries are trying to overcome to meet their local environmental regulations. In some cases, reducing emissions requires a higher energy consumption which requires a significant increase of the operating costs.

RATE conducted a feasibility study in the Middle East, where they usually operate larger sulphur plants and due to the hot climate, the energy consumption is very high. In this study, the customer had an existing regular Claus unit and was looking for options to reduce SO_2 emissions with optimised energy consumption and reasonable operating and capital costs.

One of the biggest concerns was that if they were to use a chiller to cool the quench water and the amine circulation, it would require 170 MW electricity, which would result in an electricity operating cost of several million dollars per month.

As shown in Table 1, the chiller could be eliminated with significant cost savings, while also reducing SO_2 emissions and increasing the sulphur recovery efficiency. The customer should be able to select the revamp option based on local regulations and avoid additional unnecessary investment.

ACT (Advanced Clean Technology) SO_2 emission summary

Table 2 provides a summary of the typical SO_2 emissions for the implementation of different schemes.

Other sulphur recovery schemes like sub dew point processes were not discussed because the revamp options 2–5 in Table 2 can be applied to any type of sub dew point process to achieve the desired emission according to local environmental regulations. The sub dew point process recovery range is from 98.5% to 99.5%.

There are some basic actions that can be taken to increase the recovery and to improve the operation as follows:

Table 1: **SO_2 emmission reduction options**

Options	Base case SRU & TGU	SETR after incineration	Caustic after incineration	TG-MAX technology	SMAX, SMAXB direct oxidation & reduction
Refrigeration	Yes	No	No	No	No
Sulphur recovery efficiency	99.91%	99.99%	99.99%	99.95%	99.5%, 99.99% with caustic
Catalysts	Al, Ti, CoMo catalyst	Al, Ti, CoMo, SETR ADS 700 catalyst	Al, Ti, CoMo catalyst	Al, Ti, CoMo, hydrolysis catalyst	SMAX 100, AM, SMAXB 100, Al, Ti catalyst
Chemical	Flexsorb or similar	Formulated MDEA	Formulated MDEA, caustic	Formulated MDEA	Caustic
Utility, steam, BFW	Base	Base	Base	Base	Lower than Base, no TGTU
Power refrigeration	170 MW	0	0	0	0
Fuel gas, Gcal/day	6,300	6,300	6,300	6,300	6,300
HP steam, export, t/d	25,000	25,000	25,000	25,000	25,000

Source: RATE

Table 2: **Summary of SO_2 emission scheme**

Option	Description	SO_2 emission
1	Conventional tail gas treating with MDEA solvent	150-250 ppm
2	TG-RATE, conventional tail gas treating with selective solvent	50-60 ppm
3	TG-SMAX - tail gas treating with selective solvent plus new innovation hydrolysis reactor, plus recycle pit vent	25-30 ppm
4	TG-caustic, tail gas incineration – caustic scrubber	0-10 ppm
5	SETR – Super Enhanced Tail Gas Recovery	0-5 ppm

Source: RATE

- Use a high intensity SRU burner for better destruction of ammonia, hydrocarbons and impurities.
- Use titanium catalyst at the bottom of the first SRU reactor bed and alumina at the top. The volume of the Ti catalyst could be up to 50% of the total catalyst volume.
- Recycle the vent gas from the sulphur pit and sulphur degassing, which is traditionally routed to the incinerator, to the front of the SRU. It is very important that the recycle gas is routed to the proper location to prevent any cold spots or plugging as well as any impact on the SRU recovery.
- Select formulated amine solvent instead of generic MDEA in the tail gas unit to achieve 10 ppmv of H_2S from the absorber overhead.

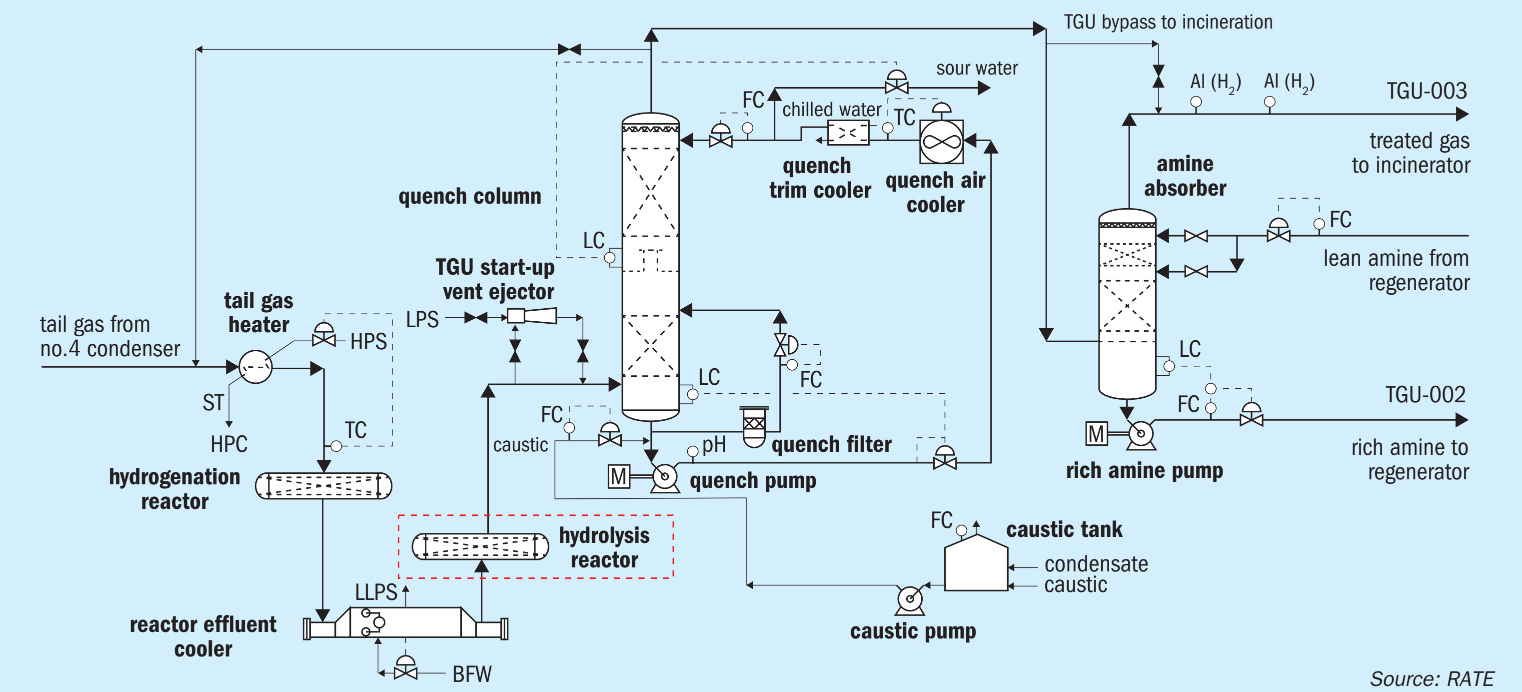
Increasing sulphur recovery with advanced catalysts[2]

There are still many countries that do not require very tight SO_2 emissions but are nevertheless looking for a sulphur recovery rate of above 98%. RATE SMAX and SMAXB technology is a patented technology (US Patent US 9,023,309 B1), which offers schemes based on advanced catalysts.

Short descriptions of the retrofitting of existing SRU modifications from some current projects are listed below:

- **Retrofitting existing two-stage Claus to 2+1 SMAX:** requires adding a third reactor (with selective oxidation catalyst) to the existing two-stage Claus SRU. Most of the work can be done as add-on, skid-mounted units with no need to shut down, however, tie-in of the third reactor, piping, instruments, utilities, etc. requires approximately two weeks of unit shutdown and will improve the sulphur recovery efficiency from 95% to 99% or 99.1% depending on the H_2S concentration.
- **Retrofitting existing two-stage Claus to 3+1 SMAX:** requires adding a third reactor (with conventional Claus catalyst) and a fourth reactor (with selective oxidation catalyst) to the existing two-stage Claus SRU. Again, most of the work can be done as add-on, skid-mounted units with no need to shut down, however, tie-in of the third and fourth reactors and associated piping, instruments, utilities, etc. requires two to three weeks of unit shutdown and will improve the sulphur recovery efficiency from 95% to 99%-99.4%.
- **Retrofitting existing two-stage Claus to keep 2 + 1 SMAX:** requires changing the catalyst in the second existing reactor (with combined conventional Claus + reduction catalyst) and adding a third reactor (with selective oxidation catalyst) to the existing two-stage Claus SRU. Again, most of the work can be done as add-on, skid-mounted units with no need to shut down, however, tie-in of the third reactor and associated piping, instruments, utilities, etc. requires three to four weeks of unit shutdown and will improve the sulphur recovery efficiency from 95% to 99.2%-99.3%.

Fig. 2: **TG-MAX hydrolysis reactor**



Source: RATE

- **Retrofitting existing two-stage Claus to 3+1 SMAXB:** requires adding a third reactor (with combined conventional Claus + reduction catalyst) and a fourth reactor (with selective oxidation catalyst) to existing 2-stage Claus SRU. Again, most of the work can be done as add-on, skid-mounted units with no need to shut down, however, tie-in of the third and fourth reactors and associated piping, instruments, utilities, etc. requires three to four weeks of unit shutdown and will improve the sulphur recovery efficiency from 95% to 99.2%-99.6%.
- In all four options listed above the H_2S-containing pit vent from the sulphur pit or degassing can be recycled to the front of the SRU instead of the incinerator to increase the sulphur recovery. It requires additional cost to recycle the pit vent stream.

In some cases, the third condenser and the fourth reheater after the SMAXB is eliminated as the SMAXB reactor provides an adequate temperature to the SMAX reactor.

Changing the catalysts and the number of required Claus reactors depends on the target desired sulphur recovery. In some cases three existing reactors may be adequate, in others a fourth reactor may be needed. Sometimes changing to SMAX 100 catalyst only may be adequate in the last Claus reactor but in other cases both SMAX 100 catalyst and SMAXB 100 catalyst may be required. It all depends on the feed stock to the sulphur recovery and the desired new local environmental regulations. It is therefore important to conduct a study before selecting the revamp option.

Conventional tail gas treating unit

The conventional tail gas treating unit includes a low temperature hydrogenation catalyst, quench system and the amine unit which many facilities around the world have already added to their sulphur recovery units. Some SRUs, mostly in the United States, have also added a caustic scrubber after the incinerator to meet the new World Bank SO_2 emission requirements.

TG-MAX tail gas treating unit

TG-MAX can be added to the Claus Sulphur recovery unit as a new unit, or the conventional tail gas treating unit can be upgraded to TG-MAX (a RATE patented technology: US Patents US 10,752,502 B2 and US 9,624,106 B2).

The RATE COS/CS_2 hydrolysis reactor in the TGTU, is an additional reactor after the hydrogenation reactor to maximise the hydrolysis of COS and CS_2 and to minimise SO_2 emissions. It eliminates the caustic scrubber and spent caustic disposal after the incinerator. Fig. 2 represents TG-MAX with the hydrolysis reactor, and with pit vent recycled to the sulphur recovery reaction furnace.

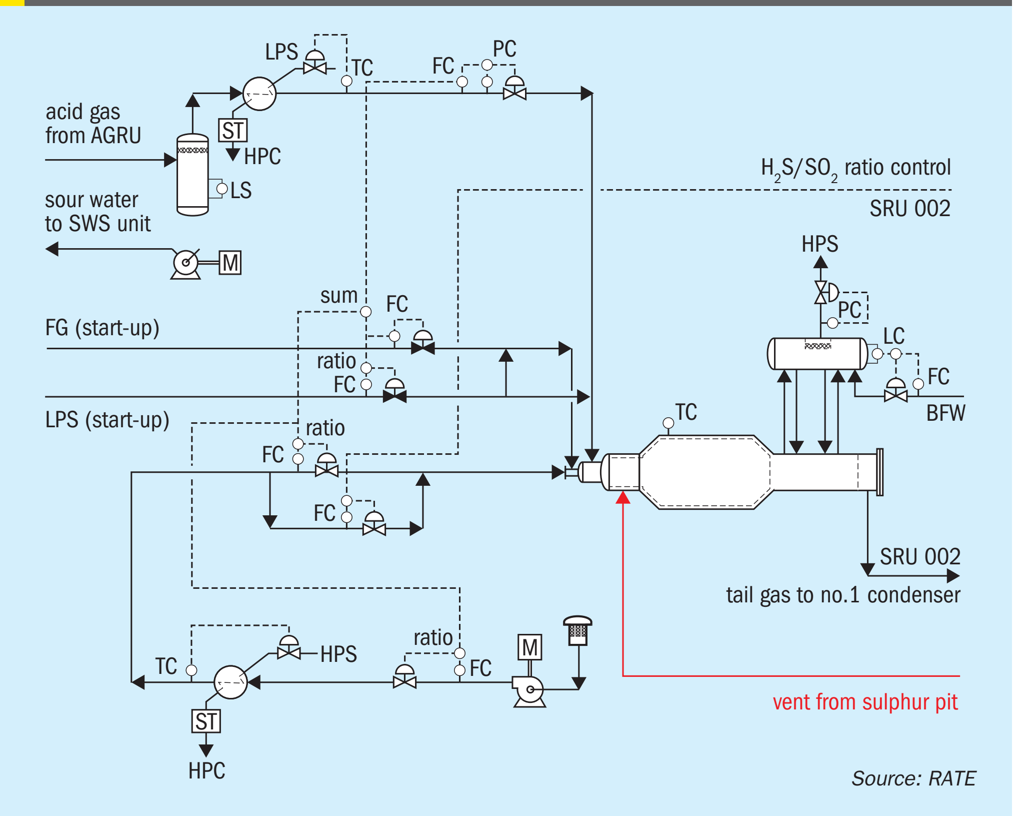
The tail gas unit includes the hydrogenation reactor with low temperature hydrogenation catalyst. As part of the new invention an additional reactor is added, the so-called hydrolysis reactor, with both reactors in one shell to hydrolyse the remaining of COS and CS_2 and any sulphur compounds. Based on actual operating data the amount of COS and CS_2 is approximately 30 ppmv after the hydrogenation reactor.

As part of a new patented innovation, the remaining COS and CS_2 is hydrolysed in the hydrolysis reactor. The gas is cooled and flows to the quench system where additional water is condensed before being processed in the tail gas amine unit using formulated selective solvent where the absorber overhead will have less than 10 ppmv of H_2S.

Based on this scheme, the SO_2 emission from the stack will be around 25-30 ppmv depending on the acid gas composition to the sulphur plant and how much COS and CS_2 are produced and hydrolysed.

The sulphur pit vent and sulphur degassing vent are collected, the pressure is boosted and then recycled back to the SRU reaction furnace instead of incineration (Fig. 3).

Fig. 3: **Sulphur pit vent and degassing vent to reaction furnace**



Source: RATE

Super Enhanced Tail gas Recovery (SETR) technology

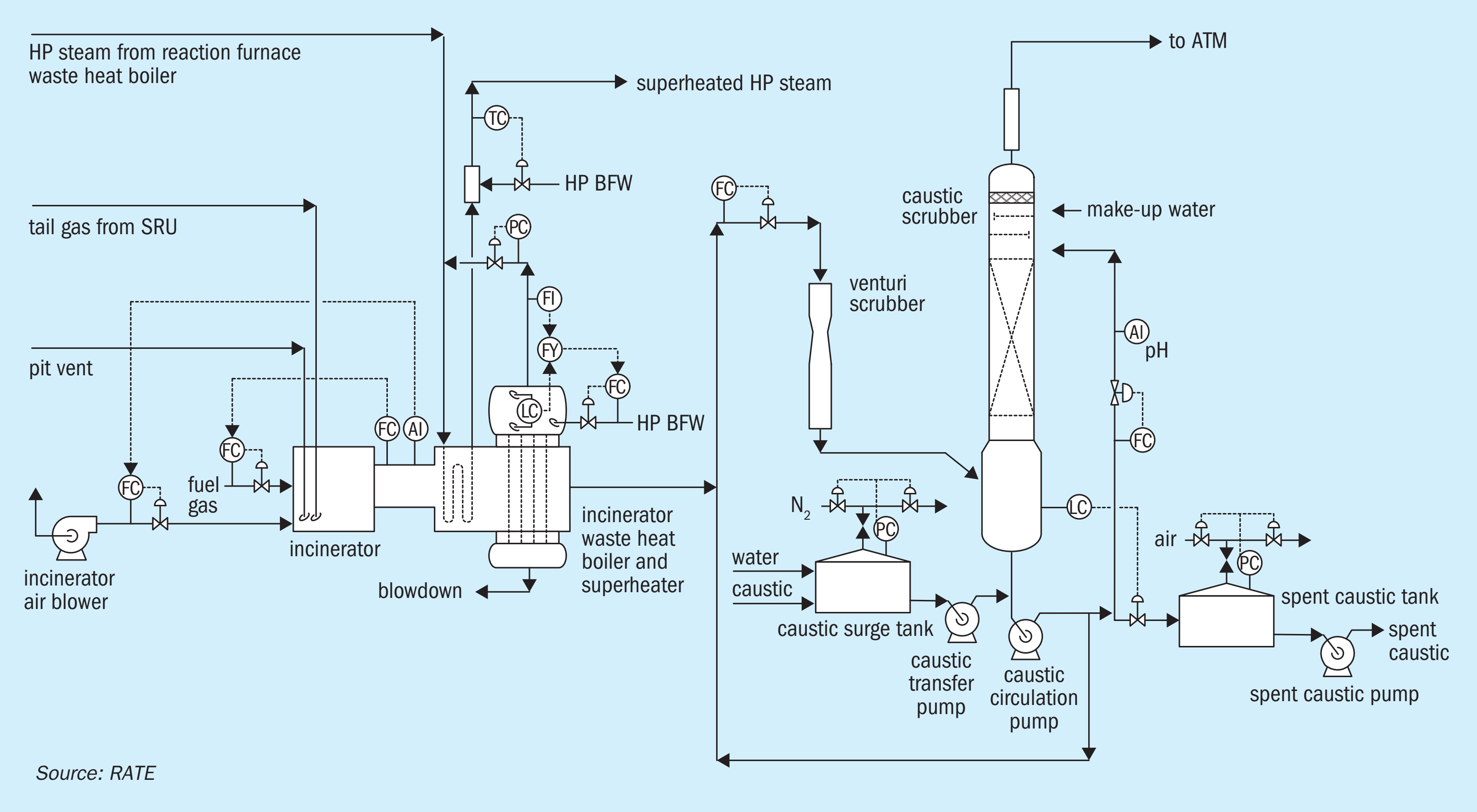
SETR is another patented technology (US patent number US 10,689,254 B1) which is located after incineration and before the stack. It can be applied after any type of a tail gas treating unit to increase the sulphur recovery beyond 99.5%, without the need for conventional tail gas treating. Sulphur is recovered and recycled back to the SRU. In contrast to caustic scrubbing, which generates a waste stream, there is no waste stream from SETR. The SETR scheme will improve recovery efficiency from 99.5% to 99.9%-99.99%.

Retrofitting an existing two-stage Claus to SMAX / SMAXB plus SETR can achieve the ultimate sulphur recovery or zero SO_2 emission.

The catalyst used in this process is SETR ADS 700, an activated alumina-based adsorbent with a catalyst life of four to five years, the same as Claus catalysts.

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

Fig. 4: **Tail gas incineration with caustic**



This process consists of the adsorbent and regeneration reactors. The SETR reactors switch between adsorption and regeneration modes. They are located after the tail gas incineration and before the stack replacing any type of the caustic scrubber system. The innovative SETR process is not a sub dew point process where the bed becomes saturated with sulphur, instead, the SETR process has fixed bed reactors that require heat up and cool down for the SO_2 adsorption-based Claus tail gas process. The adsorption mode operates at a cold temperature to adsorb the SO_2.

The SETR process is a cost competitive solution that converts unrecovered sulphur compounds to sulphur, without the need for chemicals, and without generating any waste streams.

Tail gas thermal incineration with caustic scrubber

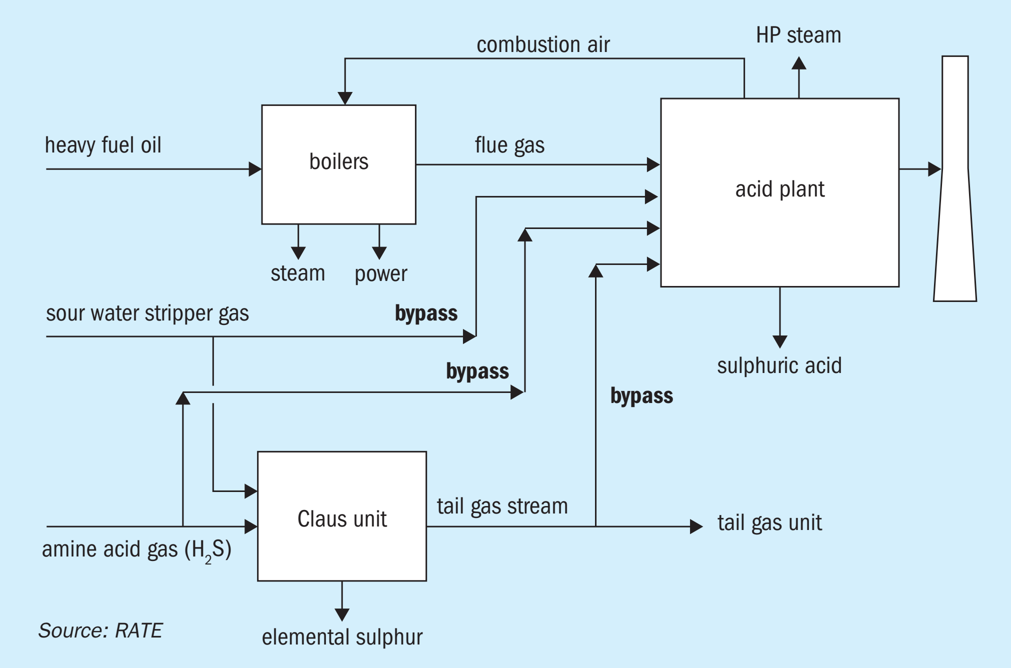
RATE is working with US government agencies that are mandating that existing operating SRU and TGUs control their SO_2 emissions to meet 10 ppmv of SO_2. RATE has been designing additional units for some of these projects and is supporting environmental regulation agencies in the US to control stack emissions in existing facilities. In some cases where the sulphur plant has no back-up tail gas unit, it is requested to install a caustic scrubber after the catalytic incinerator (Fig. 4).

The waste caustic can be sent to the existing water treatment system or it can be neutralised and drained to a safe location.

The effluent gas from the thermal incinerator waste heat boiler is desuperheated in a venturi scrubber by intimate contact with a 10 wt-% caustic solution. During the liquid vapour contact a portion of the SO_2 is removed from the vapour and the gas is cooled.

The liquid-vapour mixture then flows to the caustic scrubber. The vapour flows up through the packed bed of the caustic scrubber against a countercurrent stream of 10 wt-% caustic solution to scrub the remaining SO_2 from the tail gas. The treated gas leaving the caustic scrubber will contain low ppm levels of SO_2. With this scheme zero emission of SO_2 (0-10 ppm) from the tail gas incineration can be achieved.

Fig. 5: **Claus tail gas conversion to sulphuric acid**



Sulphuric acid production

Sulphuric acid plants are well known in industry, mostly for the conversion of SO_2 to acid in the following applications:

- sulphuric acid production & recycling;
- mining and roasting industry;
- viscose fibre industry;
- petrochemical industry;
- tail gas treating units (recent).

There are some refineries around the world that are able to produce sulphuric acid and to market the acid that is surplus to requirements for internal consumption.

In some new sulphur projects, tail gas units have been eliminated due to their high cost to achieve near 100% sulphur recovery and have instead been replaced by a sulphuric acid plant to eliminate SO_2 emissions to the atmosphere.

In new refineries the concept of using a sulphuric acid plant as the tail gas treating plant allows any vent gas, or tail gas feed that contains sulphur compounds, to be routed to the acid plant.

In this option (see Fig. 5), the TGU amine unit and the incineration system is completely eliminated and the tail gas from the SRU is routed to the sulphuric acid plant. The vent gas from the sulphur pit and the sulphur degassing could be routed to the front of the SRU or to the sulphuric acid plant directly. An overall sulphur recovery of nearly 100% can be achieved.

Another benefit of acid plant technology is if the refinery has to process crude with high nitrogen content. The sour water stripper ammonia gas may be beyond the capability of the sulphur plant but could be processed in the acid plant.

Catalytic tail gas incineration

Catalytic tail gas incineration (CTI) can also be regarded as a backup tail gas unit. Catalytic incineration can be used to reduce CO_2 emissions and the fuel consumption of thermal incineration. In the past, RATE has designed its CTI unit with a caustic scrubber system, where less than 10 ppmv of SO_2 could be met.

Recently RATE conducted a study to offer CTI-MAX in combination with the production of ammonium sulphate as a saleable product in a refinery application where pure ammonia was available. The existing sulphur recovery units were a three-stage Claus unit, and a three-stage Claus unit with direct oxidation similar to SMAX. Adding CTI-MAX and producing ammonium sulphate was attractive because both ammonia and SO_2 could be used to make a saleable product.

RATE also licenses a two-stage sour water stripper which produces a high purity ammonia stream.

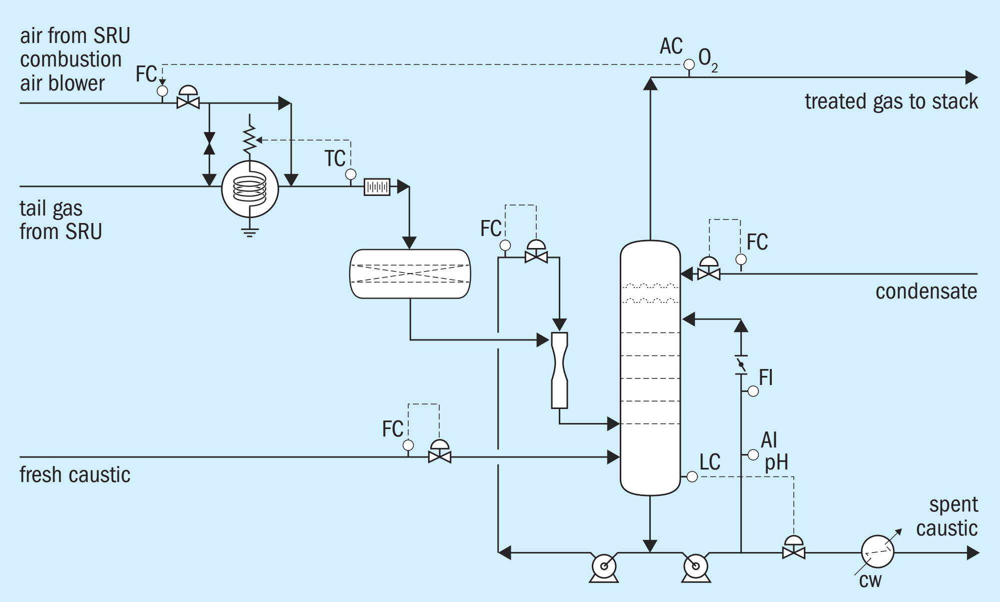
CTI-MAX is a catalytic tail gas incineration option which uses TGU low temperature catalyst and selective direct oxidation catalyst.

The gas leaving CTI-MAX can go to the incinerator or other units for processing SO_2, such as a Cansolv unit or a caustic scrubber. Alternatively, if pure ammonia is available from a two-stage water stripper, ammonium sulphate or ammonium thiosulphate can be produced.

This process eliminates NG consumption from the conventional RGG by using an indirect heater, reduces fuel gas consumption in the incinerator, and reduces emissions.

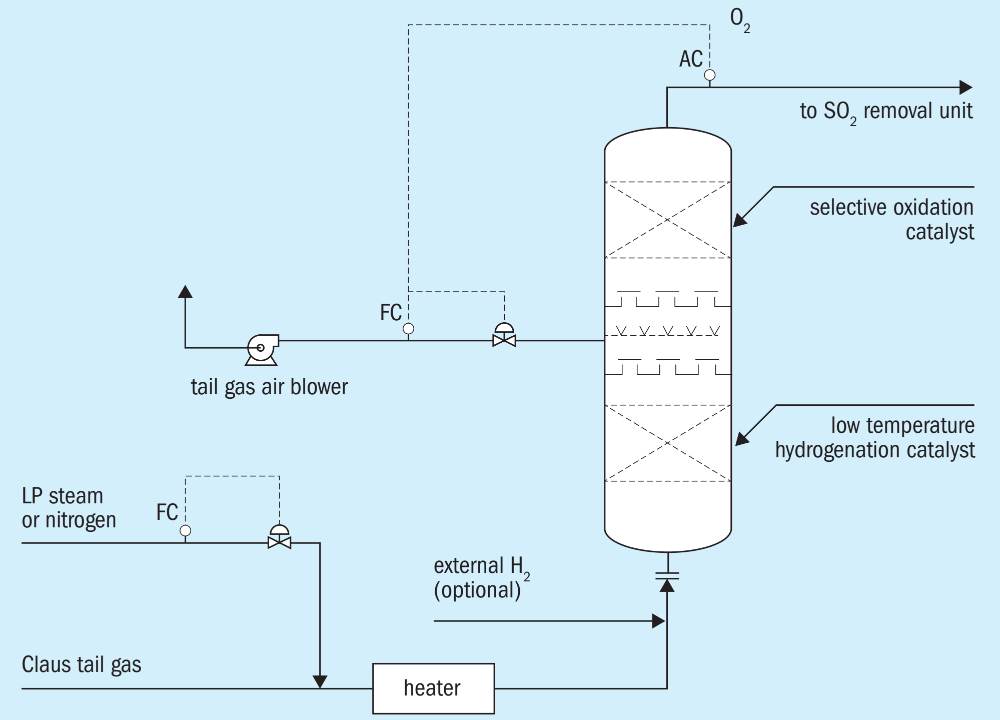
Fig. 6 shows a schematic of CTI with a caustic scrubber and Fig. 7 shows a schematic of CTI-MAX.

Fig. 6: **CTI with caustic scrubber**



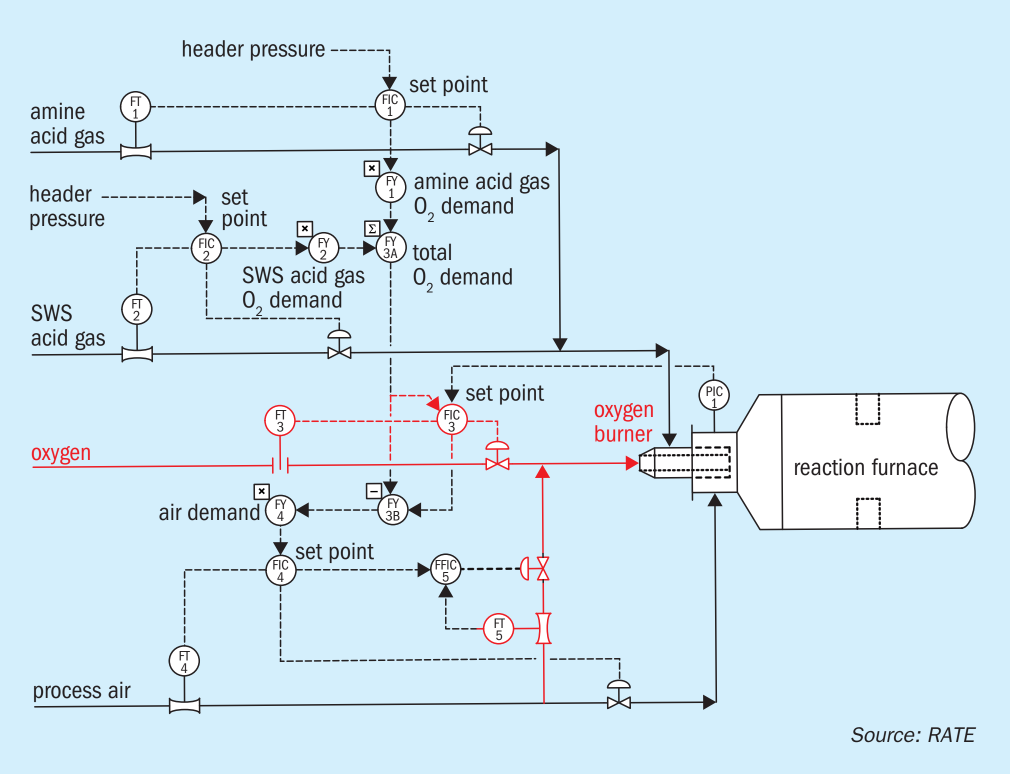
Source: RATE

Fig. 7: **CTI-MAX**



Source: RATE

Fig. 8: **Sulphur recovery revamp with low or mid-level oxygen enrichment**



Source: RATE

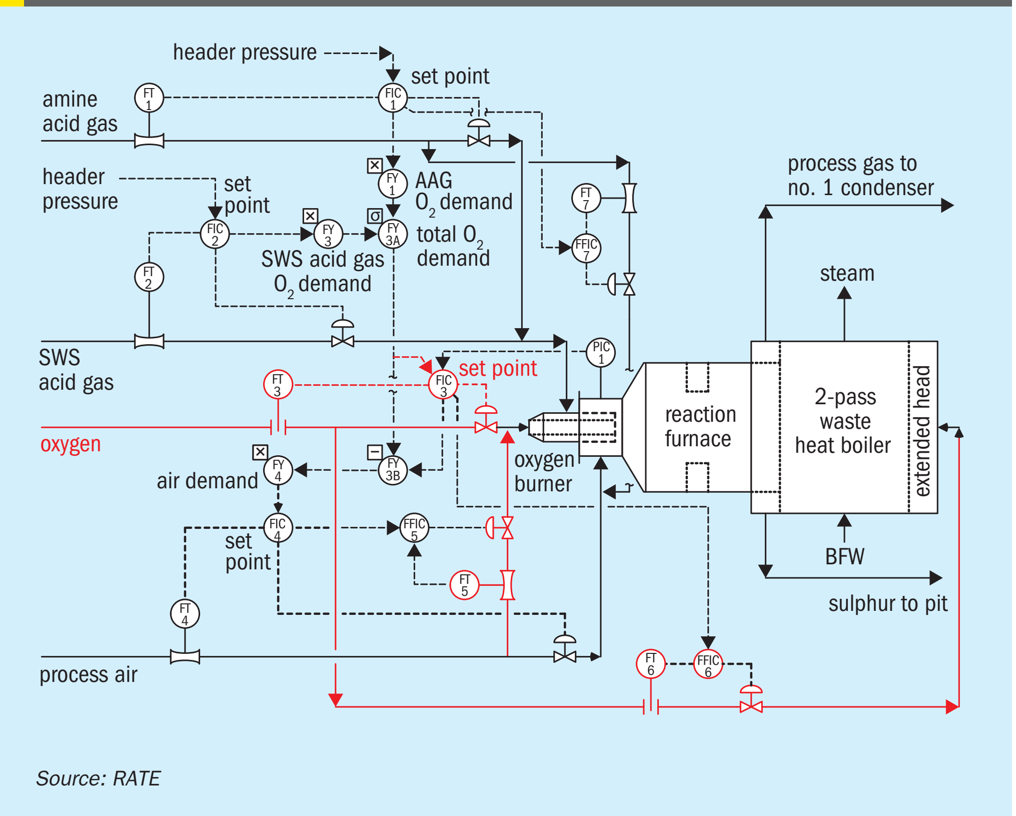
IMO Compliance with oxygen enrichment[3]

The results of implementing IMO 2020 globally means additional sulphur will be removed from other units and sent to the existing sulphur recovery units. Oxygen enrichment can be used to cope with the increased load to the SRU. Low to mid-level, and high level of oxygen enrichment can be implemented depending on the required additional capacity. In addition to capacity increase, oxygen enrichment can be used in lean H_2S applications to increase the recovery and to reduce CO_2 and SO_2 emissions.

Figs 8 and 9 show the control system and equipment modifications for using low to mid-level and high level of oxygen enrichment accordingly.

To comply with SO_2 emissions, one of the schemes already discussed can be implemented.

Fig. 9: **Sulphur recovery revamp with mid or high level oxygen enrichment**



Source: RATE

Conclusions and summary

Sulphur plant revamps to meet future challenges fall into three main categories: CO_2 removal, SO_2 emission reduction, and compliance with IMO 2020.

There are many discussions taking place every day, in regard to CO_2 removal but no particular solutions have been implemented.

With regard to SO_2 emission reduction, there are still many countries, for example, Canada, Mexico, Russia, CIS region, part of the Middle East, among many others, that only have a three-stage conventional Claus unit and significant amount of SO_2 is emitted through the stack. Therefore, focusing on reducing SO_2 emission should be a priority. Local regulations vary from country to country and even in different regions and cities within a country. In most part companies are looking for solutions with minimum operating and capital costs, minimum shutdown during the revamp and no pre-investment. It is therefore important to evaluate each case carefully to select the best option to meet requirements.

In this paper, eight different solutions are recommended that result in different SO_2 emission levels. RATE technologies for the ultimate goal of achieving near zero SO_2 emissions and World Bank requirements are also illustrated, for example, TG-MAX Technology specially for large gas plants dealing with very large existing sulphur plants.

Finally, IMO regulations will result in additional sulphur to the sulphur recovery unit. Oxygen enrichment can be implemented as part of a revamp to accommodate the additional capacity in existing SRUs and is also one of the recommended solutions for reducing SO_2 emission levels.

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