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

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Number 372 September | October 2017

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Sulphur recovery trends

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Cover: *Skyline and reflections of midtown Atlanta, Georgia in Lake Meer from Piedmont Park.*
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Sulphur transport and handling regulations.

Wet ESP designs
Modern gas cleaning and emission control strategies.

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NUMBER 372 SEPTEMBER | OCTOBER 2017

CONTENTS

REGULARS

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1 36
2 37
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

A solution to Canada's pipeline conundrum?

People in the sulphur industry are used to innovation coming from the University of Calgary in Alberta, mainly via Alberta Sulphur Research Ltd (ASRL). However, Innovate Calgary, the University's technology commercialisation organisation, co-owned by the City of Calgary and the Chamber of Commerce, has recently come up with a development which may prove to have far-reaching consequences for the oil sands business that is one of Alberta's most profitable industries, and hence for the sulphur industry as a whole.

The problem is that shipping the bitumen extracted from oil sands to market can be a costly and inefficient process. It must be diluted, typically with lighter petroleum products such as natural-gas condensates or naphtha, to produce 'dilbit' (dilute bitumen), or upgraded to produce 'syncrude' (synthetic crude), after which it can be transported as a liquid, by rail car, truck or pipeline. However, pipeline schemes to bring Alberta bitumen to market have all run into environmental or other opposition, and whether the syncrude is exported west to the coast, south to the United States, or east to refineries in Canada's industrial heartland, the Northern Gateway, Keystone XL and TransCanada lines have all run into difficulties of one sort or another, and none currently look like being completed. This has left Canada to export by rail car to the US Gulf Coast, but here it faces problems of sheer capacity, as well as the potential for spills and mishaps during any derailment, something that has happened several times over the past few years and left US authorities moving to tighten regulations on rail transport.

> **Shipping the bitumen extracted from oil sands to market can be a costly and inefficient process.**

Is there a solution? Researchers at the University of Calgary think that there is. They have developed a way of producing pellets of heavy oil/bitumen at high speeds to produce a solid, 'granulated' form which can be transported in conventional rail cars and which is safe in the event of accidental spillage. The pellets denature the outer surface of the bitumen to produce a shell of asphaltenes, giving it an inert, unreactive outer coating which reduces its potential to harm the environment. They can even be designed to be buoyant by incorporating gas bubbles into the pellets, avoiding any risk to water courses. One major advantage is that it removes the need for diluents, which often have a market value themselves, as well as making storage and handling much easier and safer. At the far end, the pellets can be reconstituted back to bitumen to be upgraded in the regular way, or they can be used in their pellet form. The pellets can also be used directly in road paving, without the need to upgrade the product any further, according to Innovate Calgary.

The process, for which a patent is pending, reportedly uses "about the same amount of energy as it takes to add diluent to the bitumen to liquefy it", and so in theory should not be any more costly, aside from the relatively modest capital cost of the pelletising machinery. The next hurdle will of course be scale-up. Innovate Calgary has been in touch with industry partners and is aiming to begin field trials in November this year, scaling up to a "hundreds of barrels per day" commercial scale unit in 2018.

Richard Hands, Editor

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Price trends

MARKET INSIGHT

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

SULPHUR

Price run

Global sulphur prices breached the US$100/t f.o.b. Middle East mark in August, buoyed by the upward momentum achieved in Chinese delivered prices for spot volumes. The continued strength in the market has been met with mixed views due to the lack of support in downstream product pricing. However, short term supply and demand dynamics in the sulphur market have led to the upturn and look set to continue through September. China has been the main driver, due to domestic supply tightness and inventory deterioration.

On the supply front, there have been developments impacting the balance in the market. The Kashagan project in Kazakhstan had been expected to begin exporting sulphur in September but this looks set for further delays, now starting towards the end of the year. At capacity, the project would produce over 1 million t/a of sulphur for the export market. While sulphur has already been produced at the project in recent months, this has been moved to storage ahead of any export tests. This delay has added a firmer view for the final months of the year, particularly approaching the winter season as shipments from Russia usually see a seasonal downturn once the Volga Don waterway is closed.

Another project set back has been the added delay to the Rasgas Barzan project in Qatar. Previously pegged for start-up in mid-2018, the project is now not due online until the end of 2018 or potentially the start of 2019. This shift provides a more balanced outlook for the upcoming year, as the project was expected to add close to 1 million t/a of sulphur to the export market at capacity.

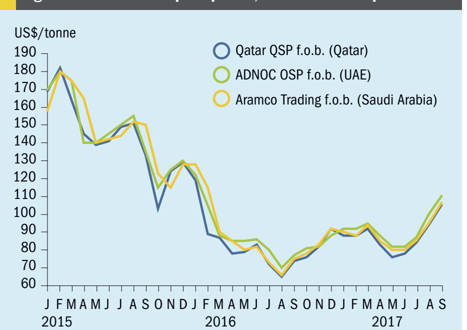
Middle East producer prices for September were posted at further increases on August. In the UAE, Adnoc announced its Official Selling Price (OSP) at $110/t f.o.b – up by $10/t on the August price. In Qatar, the QPSPP price was posted at $105/t f.o.b. Ras Laffan – a price not seen in Qatar since the start of 2016. In Saudi Arabia, the September price was announced at $106/t f.o.b. Jubail. With major projects for supply seeing further delays we would expect to see Middle East producers maintaining high prices into the latter months of the year. However, downward pressure may ensue from end users in the processed phosphate sector as equivalent price increases are not being seen in the downstream markets.

Developments in China have been a driver of the current pricing momentum. Sulphur inventories at the nine major ports eroded further down to 1 million tonnes at the end of August. While there has been a disconnect in the relationship between China's stocks and pricing recent years, this does point to import enquiries remaining healthy in the short term – which may keep prices buoyant. The local production situation has exacerbated the situation due to periods of tightness from refineries and gas plants. Spot prices in China increases from the mid-$90s/t c.fr in June to the mid-$120s/t c.fr in August, boosted by local requirements. However, despite the interest in spot volumes and price run, sulphur imports to China in January – July 2017 show a 1 million tonne drop year on year and also reflect a reduction on 2015 levels. Volumes from leading supplier Saudi Arabia are down by 25% but supply from the UAE and Iran have seen increases by 9% and 16% respectively.

The Indian market has also firmed into the $120s/t c.fr in August, following international developments despite initial buyer resistance. Firmer prices in the sulphuric acid market may also have motivated some buyers to sulphur purchases. Recent deals include FACT's 25,000 tonne purchase at $120-121/t c.fr via Swiss Singapore and CIL securing 25,000-30,000 tonnes from Transglobe for mid-September delivery.

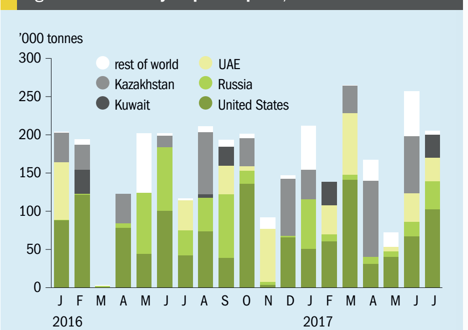
In North America, focus turned to the devastating impact of Hurricane Harvey and the potential impact this would have on sulphur operations along the US Gulf coast. Several plants were heard to be facing major disruptions due to flooding. The extent of the sulphur losses are yet to be quantified but would likely lead to further tightening of the market in the short term. The main market for US Gulf exports is Brazil, with potential impact on requirements in the coming month or longer. Brazilian imports in the period to July this year have seen a marked improvement on 2016 levels, up by 26% to 1.3 million tonnes. The US represented 37% of imported volumes. Options for Brazilian buyers in the absence of US tonnage would include FSU and Middle Eastern suppliers.

Fig 1: **Middle East sulphur prices, Jan 2015 to Sept 2017**



Source: Integer, ICIS

Fig 2: **Brazil monthly sulphur imports, Jan 2016 to Jul 2017**



Source: Integer, GTIS

SULPHUR
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Spot prices had firmed to $95-100/t c.fr Brazil in August, but were likely to rise moving into September due to the potential supply disruptions.

Over in NW Europe, fourth quarter contract negotiations are due to start in late September, with the summer period in Europe keeping the market subdued. The balance in the local market has been ample recently in most areas, but the global price developments will likely play a talking point in negotiations. There has been pockets of regional tightness but overall refinery run rates were deemed healthy.

The global supply/demand balance for 2017 was expected to see a slight increase in surplus, however with various project delays and unplanned outages, this points to a more balanced market, supporting the recent price trend and market sentiment. While market sources expect to see sulphur reaching a ceiling in the coming weeks due to a lack of support in downstream demand industries, the supply side issues may prevail and keep prices on the upside.

SULPHURIC ACID

Tight supply balance

Global sulphuric acid prices showed no signs of waning approaching the end of the third quarter. Supply tightness at major smelters and ample spot demand led to firmer prices in most regions. In the Philippines, Glencore's PASAR smelter faced disruption and sources indicated force majeure had been declared, further tightening the Asian balance.

European export prices continued to increase through the third quarter – rising into the $30/t f.o.b. range. Smelter acid producers report holding low inventories and remain comfortable with contract commitments. Offshore market interest is expected to keep prices firm for the short term, with supply side issues likely to fuel the market for some time.

Prices in major importer market Chile have not moved about the mid-$80s/t c.fr, but have held firm at these levels following the spate of purchasing that began in the second quarter. Mines in the country were heard with ample inventories in August, negating the need for increased spot volumes. The expectation remains for the second half of the year to see a slowdown in spot deals to the country as well as return to a softer import schedule. In recent years, sulphuric acid imports to Chile have been in decline, but this trend saw a reversal in the first half of the year, rising by 32% year on year, due to the unexpected supply disruptions within the region. As a result, acid shipments were seen from China and Canada, while trade from Peru eased slightly. Mexican acid into Chile also saw a boost, up at close to 133,000 tonnes. European volumes to the country dropped meanwhile, with shipments from Spain and Germany down by 60% and 27% respectively.

A major driver for higher prices has been the Northeast Asian market – the balance remains stretched in the region, particularly for spot volumes, adding to the global tightness. This is likely to continue into Q1 2018 due to the turnaround schedule at major smelters, supporting higher prices into the new year. The lack of availability has been reflected in the drop in trade from both Japan and South Korea. In Japan, the first half of the year has seen acid exports down 10% year on year at 1.4 million tonnes. Contract commitments remain the main focus for suppliers and offtakers of Japanese acid due to the limited surplus. Over in South Korea, exports slipped by 9% in the first half of the year, with the months of February and July seeing significant downward pressure from supply disruptions. Monthly volumes would usually be well above 200,000 tonnes but dropped below this mark. South Korean exports are expected to recover sooner than Japan, but the high pricing situation is expected to prevail for the foreseeable future.

Underlying demand in the Brazilian market has been strong, also supporting the upward price trajectory despite a slight slowdown in spot enquiries through the month of August. January – July 2017 imports of acid were up by over 35% year on year, with Belgian volumes seeing a major recovery following the 2016 drop to just 30,000 tonnes. This compares to close to 100,000 tonnes shipped year to date. The second half of the year is expected to remain healthy, with a more positive sentiment emerging in downstream markets to support acid pricing and trade to the country.

Price indications

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

Cash equivalent	March	April	May	June	July
Sulphur, bulk ($/t)					
Vancouver f.o.b. spot	81	78	74	81	88
Adnoc monthly contract	95	88	82	82	87
China c.fr. spot	98	91	91	97	105
Liquid sulphur ($/t)					
Tampa f.o.b. contract	75	70	70	70	74
NW Europe c.fr.	121	117	117	94	94
Sulphuric acid ($/t)					
US Gulf spot	38	38	38	45	48

Source: various

SULPHUR
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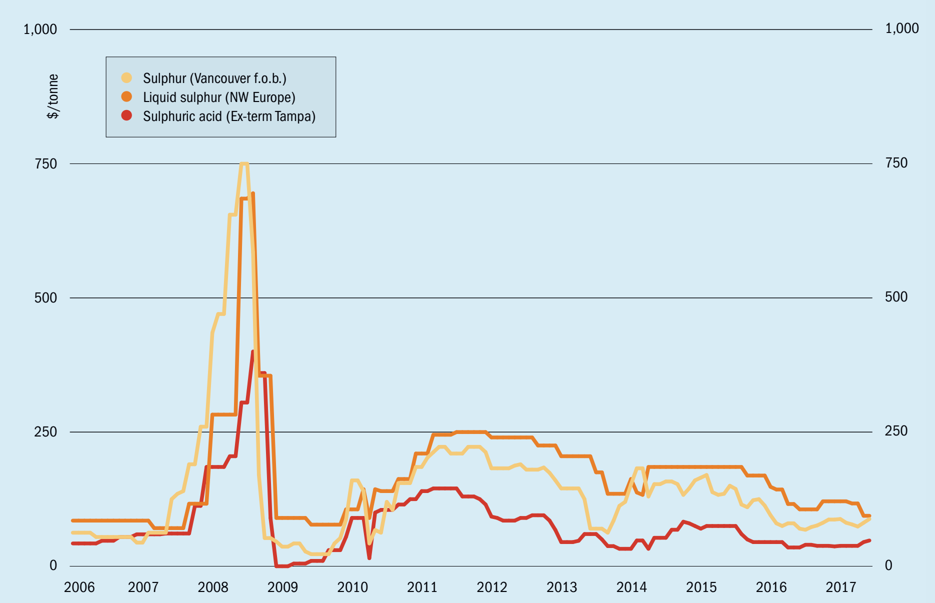
Market outlook

Historical price trends $/tonne



Source: BCInsight

SULPHUR

- The extent of potential disruption to sulphur supply in the US remains unclear and this may prove a bullish market factor in the run up to the fourth quarter.
- Sulphur consumption is set to rise in the Middle East with the start-up of Ma'aden in Saudi Arabia – this has wider implications for the processed phosphates sector as it remains to be seen how quickly the project will ramp up to capacity. Sulphuric acid has started to be produced at the plant.
- China's import volumes in the final months of the year may point to the expected decreases for the years ahead, as domestic production ramps up and demand growth prospects slowdown.
- Morocco remains a hotspot for sulphur demand and imports in the outlook, as OCP continues to ramp up its processed phosphates production.
- **Outlook:** Sulphur prices are likely to remain on a firmer footing in the short term due to the supply issues across regions as well as the approach to the winter season in the coming months. In Canada and Russia, logistics can be impacted by weather during this period. At the same time, buyers are likely to resist the continued price increases ahead of fourth quarter contract negotiations due to the lack of positive price sentiment in major markets such as processed phosphates.

SULPHURIC ACID

- Despite concerns of Moroccan acid imports waning, first half 2017 imports were up year on year by 6% at over 700,000 tonnes. Likely trade for the year is on track to be around the 1 million tonne mark.
- Northeast Asia smelter turnarounds are bolstering the outlook for this region through the start of 2018, with trade expected to remain sluggish in the second half of 2017.
- The duration of the outage at the PASAR Philippines smelter could also support regional prices in Asia. However, there is uncertainty around how long the plant will be down.
- Acid trade to China continues to erode, with January – July 2017 imports down by almost 16% year on year. There has been increased focus on sulphur based acid in the third quarter due to the regional tightness, and this has also supported pricing. At the same time, exports of acid from China have been strong so far in 2017, up at over 310,000 tonnes in the first 7 months of the year. This is due to the high demand for spot and attractive pricing situation for the main acid exporter in China.
- **Outlook:** Global acid prices are expected to see strong support from regional tightness across parts of Asia, Latin America and Europe. The recent upturn in metals pricing is also providing improved sentiment in the copper, nickel and zinc markets – boding well for sulphuric acid in the short term. However, there are question marks over how imports to Chile will develop in the remainder of the year and strategy in Morocco. Higher elemental sulphur prices in the short term are likely to add a firmer tone to contract negotiations for the fourth quarter in some regional markets. ■

SULPHUR
ISSUE 372
SEPTEMBER-OCTOBER 2017

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Sulphur Industry News

QATAR

Barzan may be delayed to 2019

The gas leak discovered in October 2016 which has delayed commissioning of the RasGas Barzan gas project continues to postpone a start-up for the 2 bcf/d processing plant. The leak, in an upstream, sub-sea section of pipe, seems reminiscent of the issues which have dogged the Kashagan project in Kazakhstan, and current estimates are not optimistic about a start-up next year. Barzan was due to produce natural gas for domestic consumption as part of a $200 billion infrastructure programme ahead of Qatar hosting the World Cup in 2022.

A complicating factor for Qatar is the current rift with its Arab Gulf neighbours, especially Saudi Arabia, but also including the UAE and Bahrain, and latterly Egypt, which has seen Qatar accused of supporting "terrorism" and calls for it to disband its Al-Jazeera news network, which has been critical of all of the other states. The accusation is that Qatar has become too closely embroiled with Iran, which is fighting proxy wars against Saudi Arabia in the Yemen and Syria, and that Qatar has supported Islamist groups such as the Muslim Brotherhood. The upshot has been an embargo on Qatar by its neighbours which has vastly complicated the small state's air and sea travel arrangements and seen its land border with Saudi Arabia closed. Attempts by Kuwait and the USA to mediate have so far come to nothing.

The imbroglio has not slowed down the pace of new project announcements, however. Indeed, if anything it seems to have accelerated them. Qatar said in July that it plans to expand LNG production by 30% from its present 77 million t/a to 100 million t/a by 2022-24. The gas will come from a new project in a southern sector of the North Field – Qatar Petroleum announced in early April plans to develop a capacity of about 2 bcf/d for export, but the July announcement doubled this to 4 bcf/d. In the meantime, a planned merger between the two state-owned LNG giants, RasGas and QatarGas is still said to be going ahead, although a round of job cuts at RasGas which was part of cost cutting measures as a result of the merger has been postponed since the embargo began. However, the supply of gas through the Dolphin pipeline to the UAE has not been interrupted, nor, so far – have LNG exports from Ras Laffan.

The gas expansions will all necessitate an increase in Qatar's sulphur output. Ensersul says that it has been awarded an equipment supply contract from Doha Petroleum Construction Co. Ltd. for the Qatargas Common Sulphur Project Expansion at Ras Laffan. Enersul will supply two 1,250 t/d *GXM1*™ sulphur granulation units in the second quarter of 2018, for a total additional forming capacity of 825,000 t/a.

SAUDI ARABIA

Savage to supply rail services to sulphur plants

Savage Saudi Arabia has entered into an agreement with Saudi Aramco to operate one of the first industrial rail switching facilities in the Kingdom of Saudi Arabia. The rail operations will support Saudi Aramco's Wasit and Berri natural gas plants, located near the Jubail area in the Eastern Province of Saudi Arabia. Savage will perform rail switching services at the two Saudi Aramco natural gas plants using rail car movers and three Tier 3-compliant, low-emissions locomotives. The company will also provide track maintenance and track signalling system operations and maintenance. Savage Saudi Arabia will own, operate and maintain the locomotives for Saudi Aramco, and will interface with the mainline rail carrier on behalf of the two plants. These services will help facilitate the transportation of molten sulphur by rail from Saudi Aramco's Wasit and Berri plants to Ma'aden Wa'ad Al Shamal Phosphate Company's (MWSPC) new mining and processing plants in Wa'ad Al Shammal Mineral Industrial City and Ras Al Khair Mineral Industrial City.

"We're excited to bring our unique capabilities and expertise to provide world-class service for our Customer, Saudi Aramco, at one of the first industrial rail switching operations in the Kingdom of Saudi Arabia," said Kirk Aubry, Savage President and Chief Executive Officer. "Our commitment to ensure safe and efficient operations at this critical link in our Customer's supply chain will provide significant long-term value for this part of their business. Our experience in safely providing refinery services in Saudi Arabia since 2012 has opened doors to new opportunities to move and manage critical materials and provide industrial services for Customers in the region," said Aubry. "We're pleased to participate in the growth and development taking place in Saudi Arabia and look forward to working with Saudi Aramco to help meet the world's growing energy needs."

KUWAIT

Enersul to supply granulators for Al Zour refinery

Calgary-based Enersul Limited Partnership says that it has been awarded an equipment supply contract from Fluor Ltd. on behalf of the FDH Joint Venture in Kuwait. FDH is a joint venture between Fluor, Daewoo Engineering and Construction, and Hyundai Heavy Industries, and aims at providing engineering, procurement and construction services to global clients. It was selected in October 2015 by the Kuwait Integrated Petroleum Industries Company (KIPIC), a subsidiary of Kuwait National Petroleum Co (KNPC) to provide services for phases 2 and 3 of the Al Zour Refinery Project. Phase 2 of Al Zour includes a hydrogen recovery unit, hydrogen compression unit, hydrogen production units, a sour water stripper unit, amine regeneration unit, sulphur recovery units and associated tail gas treating unit (TGTU), as well as sulphur forming, conveying and storage. Enersul's contract is for the supply of four of its *GXM1*™ high capacity sulphur granulation units, each with a standard capacity of 1,250 t/d, which will be delivered in the first quarter of 2018. Overall completion of Al Zour phase 2 is set for May 2019.

UNITED ARAB EMIRATES

Adnoc continues to pursue ambitious expansion plans

The Abu Dhabi National Oil Company (Adnoc) has reiterated the company's ambitious expansion plans which form part of its 2030 strategy. As well as "maximising operational efficiencies, increasing crude oil production capacity targets, and reducing costs", the company says that it is focussing on of innovative technologies for enhanced oil recovery (EOR). It also aims to significantly capitalise on its growing experience with sour gas development, and is considering a potential $20 billion

CONTENTS

SULPHUR
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investment to develop the Hail, Ghasha, Delma, Nasr and Shuwaihat fields, which could produce 1.2 billion scf/d of natural gas. This is in addition to the previously announced expansion of the Shah sour gas field by 50% to 1.5 billion scf/d, and the continuing development of the Bab and Buhasa sour gas fields. Abu Dhabi also plans to expand downstream, increasing petrochemical production from 4.5 million t/a to 11.4 million t/a by 2025. The company is also in "advanced discussions" with more than a dozen potential partners who have expressed a significant interest in its offshore concession, currently operated by the Abu Dhabi Marine Operating Company (Adma-Opco) which expires in March 2018. The existing Adma-Opco concession will be split into two or more concessions with new terms to unlock greater value and increase partnership opportunities, although Adnoc, on behalf of the Abu Dhabi government, will retain a 60% stake in the new concession areas. Existing shareholders in Adma-Opco are BP (14.67%), Total (13.33%) and Jodco (12%). Adnoc is aimiing to boost oil production capacity to 3.5 million bbl/d in 2018.

OMAN

SRU contract awarded for Duqm refinery

A consortium led by Spanish firm Técnicas Reunidas has been selected by Duqm Refinery and Petrochemical Industries LLC (DRPIC) for the $2.75 billion EPC-1 contract to build the Duqm refinery in Oman. The project, awarded on a lump sum turnkey basis, is part of the Omani government's plans to develop the Duqm Special Economic Zone with an overall investment of $15 billion over the next 15 years, including a dry dock, harbour and related infrastructure such as roads and utilities. The refinery is scheduled to be completed in 2021.

The scope of the contract includes the engineering, supply, construction and commissioning of the 230,000 bbl/d crude distillation unit (CDU), 114,000 bbl/d vacuum distillation units, 74,000 bbl/d hydrocracker unit, 52,000 bbl/d delayed coker unit, kerosene treatment unit, 83,500 bbl/d diesel hydrodesulphurisation unit and LPG treatment units, as well as hydrogen production, sour water stripper, amine regeneration unit and three 355 t/d sulphur recovery units. These units will be designed and built under licence from the respective technology licensors, including Chevron Lumus Global. UOP, Foster Wheeler, and Fluor USA, who will license the sulphur recovery units. According to Tecnicas Reunidas, which is a majority 65% shareholder in the consortium with Daewoo Engineering & Construction, the process units will be designed at its offices in Madrid.

SWEDEN

Sandvik to divest Sandvik Process Systems

Sandvik has signed an agreement to divest Sandvik Process Systems to FAM AB, owned by the three largest Wallenberg foundations, for a price of 5.0 billion Swedish krone ($610 million). Sandvik Process Systems supplies industrial process solutions based on high-end steel belts and associated technologies, employing 600 people and with 2016 revenues of 1.7 billion SEK ($207 million), representing 2% of Sandvik's total revenues. Its products include the *Rotoform* pastillation machine, used for sulphur forming, among other applications.

"This is an important step in focusing Sandvik on its core businesses. The divestment creates additional capacity for growth and expansion of the core business of Sandvik", said Björn Rosengren, president and CEO of Sandvik. "We look forward to further develop, together with management and the employees, the Process Systems business as an independent company with strong focus on profitable growth", said Lars Wedenborn, CEO of FAM.

UNITED STATES

New H_2S scavenger for oil producers

Speciality chemicals producer Clariant has launched a new H_2S removal product which it calls *SCAVINATOR*. This is a is a water soluble scavenger for removing sulphide species from both gases and liquids and can be used to control hydrogen sulphide levels for oil producers. It can be applied in batch form (via a contact tower) or continuously injected into pipeline streams, and aims to be an alternative to triazine H_2S scavenger chemistry. Clariant says that, unlike triazine, *SCAVINATOR* does not have a propensity to produce solid reaction by-products, and has a minimal impact on pH, which reduces associated mineral scaling. This combination of benefits enhances production and minimises downtime linked to pipeline cleaning and solids' removal. Several extended trials and applications conducted with producers in the Eagle Ford Shale in South Texas have demonstrated its effectiveness in both direct injection and contact tower applications, with no impact on fluid separation.

CHINA

CPC Taoyuan starts up sulphur recovery units

The Chinese Petroleum Corporation (CPC) awarded DuPont Clean Technologies (DuPont) the contract to supply the technology license, engineering and proprietary equipment for a *MECS® DynaWave®* wet gas scrubbing unit to be installed at its Taoyuan refinery in Taiwan in August 2015. This scrubbing system has recently gone into operation for two sulphur recovery units (SRUs) at the site, in time for CPC to comply with strict emissions reduction regulations.

In the past, seven to eight days were required after turnaround of the SRUs at the CPC refinery before acid gas could be fed to the units and commence normal operation. As a result, off-gas from the catalyst would be released directly to the stack and into the air, causing environmental issues. CPC researched different solutions to resolve these issues, and finally opted for the *MECS® DynaWave®* scrubber, a scrubbing technology licensed by DuPont.

"CPC chose the *DynaWave®* scrubber for the high reliability of its outlet gas emissions when inlet gas SO_2 concentration varies," explained William Lam, senior business development manager, Taiwan and Japan. "This means there is no need to adjust *DynaWave®* equipment such as valves or pumps in order to meet strict emissions targets. The SO_2 removal efficiency of *DynaWave®* turns an average of 10,000 ppmv SO_2 at the inlet into a guaranteed outlet of less than 50 ppmv SO_2." At startup, CPC technical teams measured only 10 ppmv SO_2 at the stack outlet.

"Two 2-stage Claus units in the SRU2 and SRU3 at the Taoyuan refinery will be treated in a single *DynaWave®* scrubber," said Lam. The SRUs have a capacity of 100 tons/day (SRU2) and 200 tons/day (SRU3), respectively.

GERMANY

Shell to electrolyse hydrogen at refinery

Shell, together with ITM Power is planning to install a large electrolyser to produce hydrogen at its Wesseling refinery site at the Rheinland Refinery Complex. With a capacity of 10 MW, this would be the world's largest PEM (polymer electrolyte membrane) electrolyser. Shell says that the electrolyser will allow the refinery to tap into intermittent renewable energy sources, such as solar and wind. The refinery uses approximately 180,000 t/a of hydrogen, which is currently produced as a by-product of the refining process or through natural gas reforming. Shell and its consortium partners ITM Power PLC, SINTEF, thinkstep and Element Energy have been invited to prepare a grant agreement by the European Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU), following a competitive call for proposals.

"This would be a step into the future – opening the door to many new development options for the refinery," said Dr. Thomas Zengerly, general manager for the Shell Rheinland Refinery. The location will also allow the refinery to later expand its facilities to supply hydrogen to potential new customers outside the refinery. "This project would allow us to test new technologies in the refinery context", Zengerly said.

NIGERIA

Air Liquide to license refinery hydrogen plant

Air Liquide Engineering & Construction has been selected to supply two hydrogen production steam methane reformer (SMR) units to Dangote Group, the largest manufacturing conglomerate in West Africa. The SMR units will be core to a new hydrogen generation complex producing 200,000 Nm³/h of hydrogen and high quality steam for Dangote's new refinery located in the Lekki free trade zone east of the capital Lagos in Nigeria. The new 650,000 bbl/d refinery is part of the largest industrial complex that is currently under development in Africa and will produce Euro V-compliant low sulphur fuels, among other products. The equipment supply agreement follows a first agreement related to technology licence and process design which Air Liquide signed with Dangote in 2015.

Domenico D'Elia, vice president and chairman of Air Liquide Engineering & Construction, said: "We are proud to deliver our technology and the steam reformer packages for the large hydrogen production unit as part of this ambitious refinery project. Dangote's confidence in selecting Air Liquide's hydrogen and steam reforming technology reaffirms our leading position in this market segment, with more than 130 references around the globe "

DuPont to supply alkylation and acid regeneration units

As part of the same refinery development at Lekki, DuPont will be supplying Dangote with proprietary equipment for a *STRATCO®* alkylation unit, *MECS®* sulphuric acid regeneration (SAR) unit, *DynaWave®* sulphur recovery unit (SRU) tail gas scrubbing, and *BELCO® EDV®* fluid catalytic cracking unit stack scrubbing to help Dangote meet gasoline pool octane and emissions requirements. The new 27,000 bbl/d (1.06 million t/a) alkylation unit and the 260 t/d SAR unit will allow the facility to produce high octane, low sulphur alkylate with zero olefins, while the wet gas scrubber is designed to meet world standards for particulate matter and SOx emissions on both 115 t/d SRUs. The refinery is targeted for completion in 4Q 2019. ■

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UNITED STATES

JDCPhosphate secures finance for new demonstrator plant

JDCPhosphate Inc., based in Fort Meade, Florida, has reached a financing deal with New York-based investment firm Stonecutter Capital Management LLC, for an undisclosed sum. The company says that the new investment will allow JDC to re-tool its demonstration plant to allow for continuous production of phosphoric acid using the firm's commercialisation of the so-called Improved Hard Process. The process, named after Robert Hard, a chemical engineer who created the technology in the 1970s, is a kiln-based process which uses the heat provided from oxidation of carbon in petroleum coke (present as a reducing agent) to eliminate over 90% of the electricity consumed in the furnace acid process, and not only can operate using lower grade phosphate rock, but also produces no phosphogypsum waste. Most importantly from the point of view of the sulphuric acid industry, the process does not consume the large volumes of sulphuric acid used in conventional phosphate processing which represent 60% of all acid demand worldwide.

One of Hard's co-workers, Joseph Megy started JDC in 2008 with Theodore "Tip" Fowler, a veteran executive in the Florida phosphate industry to commercialise the process. A 1 t/h demonstration plant began operations in 2014, but issues with dust production initially prevented the plant from operating continuously. Now that this has been solved (a patent was granted earlier this year for the improvements to the process) the company is building a new demonstration plant, capable of producing 100 kg of phosphoric acid per hour (800 t/a), based on the new technology, which will begin operating in 1Q 2018 and run for 3-6 months to demonstrate continuous operation, but the ultimate aim is to move to a larger, 10-20 t/h (80-160,000 t/a) commercial scale plant.

Timothy Cotton, chief executive officer at JDC and a founding partner of Agrifos Partners LLC, the largest investor in JDC, said; "We view this as a very important step – not as important as building a full-scale plant, but a significant step. Other investors in JDC include Avenira Ltd, an Australian phosphate company, which holds the license to use the process at its facilities in Australia and Senegal, as well as Japan's Mitsui Group.

Fine for acid alkylation plant accident

ExxonMobil has been fined $165,000 by US regulators for safety lapses including inadequate training and equipment maintenance over an explosion that injured four workers at its refinery in Baton Rouge, Louisiana in 2016. The Occupational Safety and Health Administration (OSHA) issued nine citations over the November 22nd incident, which involved an explosion at a sulphuric acid alkylation unit which injured four workers, two of them severely. A worker on the alkylation unit removed the cover of a malfunctioning valve on an isobutane line and used a wrench to turn the valve stem, at which point the valve fell out, releasing isobutene which was ignited by a welding machine.

Exxon says that it cooperated fully with the OSHA investigation and that it is contesting the OSHA citations and fines, which include $63,000 for failing to carry out external visual and ultrasonic inspections of piping. A separate investigation by the US Chemical Safety Board (CSB) is ongoing and is due to report by the end of this year.

HF to sulphuric acid alkylation conversion

DuPont Clean Technologies (DuPont) has launched its new ConvEx℠ hydrofluoric acid alkylation conversion technology. The company says that this is a cost-effective solution that enables refiners to convert volatile and toxic hydrofluoric acid (HF) alkylation units to the safer sulphuric acid alkylation technology, while also offers refiners the option of significant capacity increases at minimal additional cost. Historically, the expense of converting from HF to sulphuric acid alkylation was estimated by the industry at 80% of the cost of a grassroots sulphuric acid alkylation unit of a similar size. This perceived high conversion cost and the lack of any other economic benefits deterred refiners from committing to this change. By reusing much of the existing equipment, conversion with ConvEx℠ is estimated to be approximately 40-60% of the cost of a grassroots sulphuric acid alkylation unit, representing a step-change reduction in cost. In situations where plot space is available near the existing facility, downtime can be reduced by installing new equipment during normal operations. With new equipment installation already complete, the remainder of the conversion work can be finalized within a typical 30-45 day turnaround window.

Fundamental to the expansion aspect of the technology is the difference in the way in which isobutane is recycled between the HF and sulphuric acid alkylation technologies. HF alkylation units provide all isobutane to the reaction zone by recycling it from the fractionation section, while sulphuric acid alkylation units provide half of the required isobutane from fractionation and half from the refrigeration section. This difference is significant, as conversion from HF to sulphuric acid alkylation means isobutane required from fractionation is cut in half, freeing up fractionation space and, therefore, effectively doubling the capacity of the alkylation unit without requiring any significant changes to the fractionation equipment.

"We are excited to bring this game-changing technology to market," said Eli Ben-Shoshan, global business director, DuPont Clean Technologies. "For the first time, refiners truly have cost-effective options to ensure the safety of their refinery personnel and surrounding communities, while simultaneously producing high-quality alkylate at increased rates to meet market demand."

AUSTRALIA

BHP to make big investment at Olympic Dam

BHP is investing A$600 million at its Olympic Dam operations in South Australia this financial year, according to the company. The expenditure will cover both underground and above ground operations and will involve the largest ever planned shutdown at the copper, uranium and gold mine, to ensure that the operation is more modern, reliable and can support processing of additional tonnes in the coming financial years. Some A$240 million will underpin further underground development in the existing northern mine area footprint, with a similar amount going towards a range of infrastructure projects, including a major smelter upgrade and a rebuild of the electric slag furnace, the flash furnace and the electrostatic precipitator.

As a result of the upgrade, a fall in copper production to 150,000 t/a is expected

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this financial year, but as a result of the improvements this will increase to about 215,000 t/a in 2019 and 280,000 t/a in 2022. BHP also continues to look towards heap leach technology might enable it to expand Olympic Dam production to more than 450,000 t/a. For the financial year just ended, Olympic Dam's production fell 18% to 166,000 t/a due to power interruptions and unplanned maintenance at the copper refinery. The company says that reduced revenue and extra spending at Olympic Dam will be offset by a jump in production at the giant Escondida mine in Chile.

Sulphuric acid production at the smelter is currently around 350-400,000 t/a, rising to an estimated 550-650,000 t/a once the revamped smelter is in full operation by 2022.

Kwinana to produce nickel sulphate

Elsewhere, BHP's Nickel West division is budgeting $43.2 million for a nickel sulphate project at its Kwinana nickel refinery. The company plans to become the world's biggest exporter of nickel sulphate by initially producing 100,000 t/a by April 2019, using existing infrastructure at Kwinana, with a potential stage two expansion to 200,000 t/a to follow. Nickel sulphate is used in lithium-ion battery production and the company is anticipating a continuing rise in demand for electric vehicles.

The project will produce nickel sulphate by conveying powder from the refinery's existing powder storage bins to a set of dissolution tanks where it will be dissolved in sulphuric acid from the company's Kalgoorlie nickel smelter.

PERU

Offtake deal signed for Bayovar

Focus Ventures Ltd. says that it has signed a memorandum of understanding with fertilizer trading company Keytrade AG for the offtake of up to 1.0 million t/a of phosphate rock from Focus' Bayovar 12 phosphate project in northern Peru. The agreement is for an initial five year term, with the product destined for the direct application agricultural plantation business and phosphate fertilizer markets.

Bayovar, 40km inland in the Sechura district of northern Peru, has a large resource of sedimentary phosphate rock which Focus aims to supply as direct application phosphate rock to agricultural consumers in Central and South America and Southeast Asia.


PHOTO: FLUOR

The Umm Wu'al phosphate plant under construction.

Focus says that the MoU marks a significant milestone for the company since it released the findings of its pre-feasibility study on the Bayovar 12 project in May 2016, and argues that it demonstrates that there is demand for their rock phosphate product. Focus President, Gordon Tainton, commented: "We are very pleased to have secured our first export off-take MoU for rock phosphate from the Bayovar 12 project and we are looking forward to converting this into a commercial purchase contract in the future. This first MoU covers a relatively large share of our planned future production which underpins the development of our project."

SAUDI ARABIA

Umm Wu'al begins production

Fluor says that the Ma'aden Wa'ad Al-Shamal Phosphate Company's (MWSPC) Umm Wu'al Phosphate Project in Saudi Arabia has started production of ammonia, merchant-grade acid and fertilizer. Fluor is providing overall program management services for this $8 billion megaproject, in addition to engineering, procurement and operations and readiness services for various scopes.

"As part of Saudi Arabia's Vision 2030, this world-class project will have a long-lasting impact on the region, as it diversifies the country's economy and creates local job opportunities for citizens," said Tony Morgan, president of Fluor's Mining and Metals business. "After less than four years from the start of the execution phase, we are proud to have partnered with Ma'aden to bring this facility to production. We look forward to continuing our partnership with Ma'aden in developing their next phase of mining projects in Saudi Arabia through our recently signed memorandum of understanding."

Production has begun on diammonium phosphate fertilizer, merchant-grade acid and ammonia. As one of the largest integrated phosphate fertilizer plants in the world, the facility will produce 3 million t/a of diammonium phosphate and nitrogen, phosphorous and potash fertilizers.

MWSPC is a joint venture between the Saudi Arabian Mining Company (Ma'aden), Mosaic and Saudi Basic Industries Corporation (Sabic).

SOUTH AMERICA

Outotec to deliver shutdown services to a copper smelter in South America

Outotec has been awarded a contract for shutdown services to an undisclosed copper smelter in South America. The €12 million order has been booked in Outotec's 2017 second quarter order intake. Outotec's scope of work includes the demolition and reconstruction of a smelting furnace originally designed and delivered by the company, which will occur during the third quarter of 2017.

"This order demonstrates our commitment to delivering life-cycle solutions to our customers. After the initial technology transfer we have been able to maintain, upgrade and service the plant during its entire life-time to maximize plant productivity", said Markku Teräsvasara, president of Outotec and acting head of the Services business unit.

INDIA

India revises sales tax on fertilizers

On July 1st this year, India introduced its new Goods and Services Tax (GST), a landmark tax reform which has been touted as the 'largest single tax reform since independence'. The GST will replace over a dozen central and state taxes on goods and services into one national rate for sales tax, and is hoped to boost GDP by up to 2%. All goods, except for precious stones and gold, fall into one of five sales tax brackets; 0%, 5%, 12% ,18% and 28%. Fertilizers were initially pegged to be in the 12% bracket, but hours before the launch of GST the government changed its mind and lowered the tax rate on fertilizers to the 5% band to ensure that fertilizer prices do not rise unduly and farmers' interests are protected. The government wants to double the income of farmers by 2022.

"Regarding the 12% rate of GST (on fertilizers), some felt it may increase the burden on farmers, so the consensus within the Council was to bring the rate down to 5%", explained Union finance minister Arun Jaitley, who chairs the GST Council. Pre-existing fertilizer sales taxes were in the range of 0-6%, and there worry was that a 12% GST rate could have seen retail prices increasing by Rs30-120 per 50kg bag of urea, diammonium phosphate (DAP) and potash in states like Punjab, Haryana and Andhra Pradesh, where there is currently no sales tax on soil nutrients.

RUSSIA

Sumykhimprom resumes phosphoric acid production

At the end of June, PJSC Sumykhimprom resumed operation of its production trains manufacturing granulated superphosphate and phosphoric acid after eight months of downtime. The company said in a statement that it produced 13,000 tonnes of 12% nitrogen 24% phosphate fertilizers, which were shipped to consumers in Ukraine, Bulgaria, and Moldova. Now the company's staff are working towards production of new line of complex 6:24:12 NPK compound fertilizers. The phosphoric acid line operated continuously during July. Sumykhimprom, 100% state-owned, produces titanium dioxide, sulphuric acid, yellow and red iron oxide pigments, complex mineral fertilizers and coagulants for water purification.

INDONESIA

Freeport reaches agreement over Grasberg

Freeport McMoRan has reached agreement with the Indonesian government in an acrimonious dispute over the fate of the huge Grasberg copper mine in the highlands of West Papua. According to the terms of the deal, Freeport will cede 51% majority control over the mine from its Indonesia subsidiary PT Freeport Indonesia to the Indonesian government, for a "fair market price", although how this will be calculated remains open to further discussions. Indonesia previously held a 9.4% stake in the mine. Freeport will also agree to build a copper smelter in Indonesia within five years. In return the company will be allowed to extend its operating licence for the mine to 2041, and to resume exports of copper concentrate for the five year period until the smelter is completed. Indonesian president Joko Widodo, who faces re-election in 2019, has promised to change Indonesia's relationship with major international investors. Indonesia blocked exports of copper concentrate from Grasberg in January in a dispute over royalties and operational control of assets. Exports were resumed in April, but a strike following Freeport laying off 10% of the workforce brought operations to a halt again.

Grasberg, a huge open cast pit 4,000 km up in the mountains of Papua, is the world's third largest copper mine and largest gold mine. Output from the open pit has been declining, and Freeport has drawn up a $20 billion investment plan to move to underground extraction, but had been holding off on investment until it could be certain of the terms under which it would be investing.

"Reaching this understanding on the structure of a mutual agreement is significant and positive for all stakeholders," said Richard C. Adkerson, chief executive of Freeport. "Important work remains on documenting this agreement and we are committed to completing the documentation as soon as possible during 2017." ■

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People

Peng Paternostre has announced that he is stepping down as the head of the European Sulphuric Acid Association (ESA) after eight years spent steering the organisation. In a statement to members ahead of the July General Assembly of ESA in Athens, he said that he had "decided to take up new challenges within Cefic, in the area of safety and regulations of chemicals transportation". "It is with regret that I leave such a wonderful group as ESA," he added. "It has been a true honour and a real pleasure to serve the European sulphuric acid platform for some years."

His replacement as Sector Group Manager within Cefic, the European Chemical Industries Confederation, will be **Francesa Ortolan**. Ms Ortolan, a native Italian, was previously policy advisor at Coceral, the European food and feed association, dealing with plant protection products, fertilizers, GMOs, mycotoxins and other contaminants. She has an academic background is in political sciences, with a specific focus in EU affairs, and holds a masters degree in international relations. She has worked in EU public and regulatory affairs in Brussels since 2010. She also speaks Italian, English, French and Spanish. Mr Paternostre said that she and Ms Ortolan will "work together over the summer to ensure a smooth transition".

The members of the board of phosphate fertilizer producer PJSC PhosAgro have unanimously confirmed **Andrey Guryev** as chairman of the management board and CEO of PhosAgro. A report on performance over the past four years, during which time Andrey Guryev has led the Company, as well as its development outlook, will be heard at an in-person Board of Directors meeting scheduled for the second half of August 2017. The Board also approved Andrey Guryev's simultaneous participation in the management bodies of other organisations, including president of the Russian Fertilizer Industry Association, member of the Board of Directors of the International Fertilizer Industry Association (IFA), Management Board member of the Russian Union of Industrialists and Entrepreneurs, and deputy chairman of the Higher Mining Council Association of Russian Miners.

The meeting also agreed to convene an Extraordinary General Meeting (EGM) of shareholders on 2nd October to re-elect the board of directors and amend the company's charter and the regulations on the general meeting of shareholders.

Dr. Heidi M. Peterson has been hired as Phosphorus Program Director with the International Plant Nutrition Institute (IPNI), effective from September 5th 2017. Dr. Peterson is filling the directorship previously held by **Dr. Tom Bruulsema**, who was appointed as IPNI Vice President, Americas and Research, earlier this year. Dr. Peterson completed her Ph.D. in Biosystems and Agricultural Engineering (2011) at the University of Minnesota in St. Paul. Her dissertation was titled "Estimating Renewable Water Flux from Landscape Features." She has a M.Sc. in Agronomy from Purdue University in West Lafayette, Indiana, and most recently (since 2013) she worked as a research scientist for the Minnesota Department of Agriculture. She was the lead technical expert on agricultural best management practices needed to address impaired waters issues within the state's agricultural landscapes. Dr. Peterson has also been actively collaborating since 2013 with phosphorus research scientists within tasked working groups of the Phosphorus Sustainability Research Coordination Network (PRCN), centred at Arizona State University. She has also been Adjunct Assistant Professor for the Department of Bioproducts & Biosystems Engineering at the University of Minnesota since 2014.

"Dr. Peterson comes to IPNI with significant leadership, teaching, and research experience surrounding phosphorus stewardship issues," said Dr. Terry Roberts, IPNI President. "We look forward to the impacts Heidi will have on the Institute's research and educational missions," Roberts added.

Calendar 2017/18

OCTOBER

2-6
IFA/IFDC Phosphate Fertiliser Production Technology, MARRAKECH, Morocco
Contact: International Fertiliser Society, PO Box 12220, Colchester, CO1 9PR, UK.
Tel: +44 1206 851819
Email: secretary@fertiliser-society.org

9-11
MESPON, ABU DHABI, UAE
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Email: info@universulphur.com

NOVEMBER

6-9
Sulphur 2017, ATLANTA, Georgia, USA
Contact: CRU Events
Chancery House, 53-64 Chancery Lane, London, WC2A 1QS, UK.
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

13-15
European Refining Technology Conference, ATHENS, Greece
Contact: Sofia Barros, Senior Conference Producer & Project Manager, World Refining Association
Tel: +44 20 7384 7944
Email: sofia.barros@wraconferences.com

FEBRUARY 2018

25-28
Laurance Reid Annual Gas Conditioning Conference, NORMAN, Oklahoma, USA
Contact: Tamara Powell, Program Director
Tel: +1 405-325-2891
Email: tsutteer@ou.edu

MARCH

11-13
AFPM Annual Meeting, NEW ORLEANS, Louisiana, USA
Contact: American Fuel and Petrochemical Manufacturers (AFPM), 1667 K Street, NW, Suite 700, Washington, DC 20006, USA.
Tel: +1 202 457 0480
Email: meetings@afpm.org
Web: www.afpm.org

12-14
Phosphates 2017, MARRAKECH, Morocco
Contact: CRU Events
Chancery House, 53-64 Chancery Lane, London WC2A 1QS, UK.
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

TBA
SOGAT 2018, ABU DHABI, UAE
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CENTRAL ASIA

Central Asia's sulphur surplus

While a full re-start at Kashagan remains elusive, continuing oil and gas developments around the Caspian Sea seem set to produce more volumes of sulphur in the coming years, but can this sulphur find a market?

The central Asian region is home to considerable reserves of oil and gas, much of it sour. As global demand for oil and gas continues to increase, so has oil and gas processing within the region, and consequently large volumes of sulphur are also recovered. However, the region's relative inaccessibility means that the prospects for exporting oil, gas and indeed sulphur depend very much on logistical concerns and prevailing oil and gas (and sulphur) prices.

Russia

Russia has long been the major regional producer of sulphur, from oil, gas and condensate fields in the Orenburg and Astrakhan region just north of the Caspian. Both are operated by subsidiaries of Russia's state-run gas giant Gazprom; Gazprom dobycha Orenburg LLC (DBO) and Gazprom dobycha Astrakhan LLC (GDA), respectively. The gas processed at Orenburg averages around 2-6% hydrogen sulphide, and the Zailinsky gas processing plant also processes gas from just across the border which comes from the Karachaganak field in Kazakhstan, as detailed below. The facilities were developed together during the Soviet era and still work closely. Orenburg also produces major volumes of oil, some of which is processed at the local Orenburg refinery. GDA meanwhile runs the Krasnoyarsky gas and condensate field, where reserves are put at 2.6 trillion cubic metres of gas and 400 million tonnes of condensate. Annual production is around 12 bcm of gas and 7.3 million t/a of hydrocarbon liquids. Krasnoyarsky has a high sulphur content of up to 25% hydrogen sulphide, which means that although Orenburg actually processes more gas – about 1.5 million bcf/day in 2012, compared to Astrakhan's 1.1 bcf/d, the Astrakhan Gas Processing plant is the largest producer of sulphur in Russia.

Fig 1: Oil and gas fields in the Caspian region

Russian sulphur output from Astrakhan has been stable since the 1990s at around 4.5 million t/a, with Orenburg contributing another 1 million t/a. Astrakhan's output is mainly sent to domestic markets, and Orenburg's exported. These two plants between them represent about 90% of Russia's sulphur production. Gazprom produced about 5.0 million tonnes and sold 5.5 million tonnes of sulphur in 2016, according to company statistics.

Sulphur ready for loading at Astrakhan.

New projects

While the Astrakhan fields are relatively mature, there is now considerable interest among Russian energy companies in developing offshore fields in the Russian sector of the Caspian Sea, which may have reserves of up to 270 million tonnes of oil and 500 bcm of natural gas. While Russia's development of this region has lagged behind its southern neighbours, Lukoil has now turned its attention in earnest to the northern Caspian as an alternative to falling production from its western Siberian fields, beginning with the discovery of the Yuri Korchagin field in 2000, where reserves are put at 1.5 billion barrels, followed by seven more fields over the next few years. More recently Rosneft has also taken an interest in the region, acquiring the Laganskiy block in 2013.

So far Lukoil's development of these fields has concentrated on the Yuri Korchagin field, which this year moved into its second development phase, and more recently it has begun production at its Vladimir Filinovsky field, one of the largest discoveries in Russia in the past 25 years. Total production from these fields currently runs at 140,000 bbl/d, with peak production expected to reach 300,000 bbl/d. However, oil from this sector of the Caspian, by way of contrast to the very sour crudes of Kazakhstan, has very low sulphur levels and an API gravity of approximately 44°.

Azerbaijan

Azerbaijan's exploitation of the Caspian began with the discovery of the Azeri-Chirag-Gunashli (ACG) field 120 km offshore. First tapped in 1994, ACG has come to represent more than 75% of the country's oil production, producing mainly sweet crude (0.16% sulphur). However, the field is declining, and the current production sharing deal comes to an end in 2024. Azerbaijan is looking to develop gas and condensate fields instead in order to make up for the shortfall from oil production, although the Southern Corridor export project which was designed to take Azeri gas and send it westwards has floundered in a lower price oil environment.

Meanwhile, BP continues to work on the massive offshore Shah Deniz ('king of the sea') gas field. This has around 40 tcf of natural gas in place, making it one of the world's largest gas-condensate fields, and one of BP's largest discoveries to date. Stage 1, which began operations in 2006, has capacity to produce 10 bcm/a of gas and 50,000 bbl/d of condensate, while Stage 2 will add an additional 16 bcm per year of gas. According to BP, the Shah Deniz 2 project is about 95% complete in terms of engineering, procurement and construction, and remains on target for first gas in 2018. As well as being the field operator, BP has a 28.8% stake in the operating consortium, which also includes TPAO (19%), Petronas (15.5%), AzSD (10.0 %), Lukoil (10%), NICO (10%) and SGC Upstream (6.7%). Gas at Shah Deniz is, like ACG oil, fairly sweet, and no significant sulphur volumes are expected from the production increase.

Kazakhstan

The discovery of the super-giant shallow offshore Kashagan field in 1993, the largest oil find since Prudhoe Bay in Alaska, with an estimated 1.9 billion tonnes (13 billion barrels) of oil reserves, was the cause for great excitement among oil companies. But development there, and at other sites in Kazakhstan on and offshore has not run smoothly. The other major oilfields, Karachaganak and Tengiz, were found back in the 1970s, and came onstream in 1984 and 1991 respectively.

Karachaganak is the oldest field, near the Russian border, and is operated by the Karachaganak Petroleum Operating (KPO) consortium, with partnership from ChevronTexaco (18%), Agip and BG (29.25% each), Lukoil (13.5%) and KazMunaiGaz (10%). It is the largest gas producing field in Kazakhstan, accounting for some 40% of the country's total gas production and around 13% of total liquids production. About 50% of gas production is reinjected to maintain pressure, while gas and condensate with a sulphur content of about 0.9%, is routed

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across the border to be processed at Orenburg in Russia, and hence forms part of Russia's sulphur output.

Tengiz has been the most successful, now responsible for 570-600,000 bbl/d of oil and other liquids production; about one third of Kazakhstan's total output. It also produced about 7.6 bcm of associated gas in 2016. It is operated by the Tengizchevroil (TCO) joint venture, formed in 1993 between ChevronTexaco and the Republic of Kazakhstan, with the current shareholding being Chevron 50%, ExxonMobil 25%, state-owned KazMunaiGaz 20%, and Russia's Lukoil 5%.

Sulphur output from sour associated gas processing ran at around 1.6 million t/a, initially mainly poured to block storage, until issues with fugitive sulphur dust led to a government about turn on storing sulphur and a major fine, followed by several years of melting down and selling off the sulphur stockpile, which peaked in 2006 at 9.2 million tonnes. From 2006 there was also a programme of acid gas re-injection into the reservoir as part of the Second Generation Project to cut flaring, although this also increased the sulphur output to a capacity of 2.4 million t/a. Nevertheless, the stockpile was largely depleted by 2013-14, and TCO has moved to forming sulphur instead, or selling it as liquid sulphur, while working with the government on safe and environmentally friendly methods of long term sulphur storage. Sulphur sales were 2.33 million tonnes in 2016, and production for 1Q 2017 was 590,000 tonnes, according to TCO.

The $37 billion Future Growth/Wellhead Pressure Management Project was approved in July 2016. This will boost output by another 260,000 bbl/d to 850-900,000 bbl/d by 2022, with 100% sour gas reinjection, which is not expected to affect sulphur output.

Kashagan

The largest field in Kazakhstan is the offshore Kashagan oil and condensate field, operated by the North Caspian Operating Company (NCOC), which includes ExxonMobil, Eni, Shell, Total and KazMunaiGas (KMG), each with a 16.8% stake, as well as Japan's Inpex with 7.56%, and the China National Petroleum Corp (CNPC), which bought out ConocoPhillips share. Kashagan has been a large and complex development, with technical factors complicating the project; extreme winter temperatures, and very deep strata below the seabed, hugely increases the pressure, as well as high concentrations of H2S in the oil and associated gas (ca 17%). The project had already suffered from major time and cost overruns before its start-up in September 2013, and had been dubbed 'cash all gone' by the Economist magazine, with estimates put at more than $50 billion. The field was soon shut down after the acid gas corroded underwater pipelines leading to leaks, and necessitating a complete re-laying of the pipes from the offshore gas plant to the onshore processing station. The field was able to re-start in 2016, with oil output rising to 180,000 bbl/d initially, and then ramping up to 370,000 bbl/d by the end of 2017. The associated sour gas was to be split 50-50, around half being reinjected and the rest processed onshore at Bolashak, generating 1.1 million t/a of sulphur when the project reached its capacity of 450,000 bbl/d. However, indications are that the start-up of the onshore processing plant has been delayed from mid-2017 as had originally been planned, and sour gas is currently being flared, and sulphur output so far seems to have been minimal.

Turkmenistan

Turkmenistan's oil production has steadily increased from 187,000 bbl/d in 2006 to 261,000 bbl/d in 2016, according to BP. It also has large natural gas reserves, as 17.5 trillion cubic metres in 2016, it is the fourth largest holder of gas reserves in the world, although it has faced difficulties in exploiting these due to its geographical position, and during the 1990s and 2000s disputes with Russia over pipeline access. New investment has come with Chinese money, as China sees Turkmenistan as a potential gas supplier, completing the Central Asia Gas Pipeline (CAGP) across Uzbekistan and Kazakhstan at the end of 2009.

The largest gas field, Galkynysh – described as the second largest gas field in the world, with reserves of up to 700 tcf – is actually a collection of fields, including South Yolotan, Osman, Minara and Yashlar. Other major reserves are located in the Amu Darya basin in the south-east (including the 60 tcf Dauletabad field) and in the Murgab South Caspian basins in the western part of the country. Production at Galkynysh began in 2013. The $8.5 billion EPC contracts for the three treatment plants at the gas field were awarded to Petrofac, LG/Hyundai and China National Petroleum Corporation (CNPC). Gulf Oil and Gas FZE won a $1.15 bn EPC contract to develop the production wells. Each of the three processing plants at Galkynysh can process up to 10 bcm per year of gas, and the gas from the local fields is quite sour – estimated to be about 6% H_2S. Consequently the gas plant has the capability to produce up to 1.8 million t/a of sulphur at capacity. Galkynysh Phase 2, adding another 30 bcm of capacity, is under way, with first production scheduled for 2018, and plans are also being drawn up for a third phase to take production to 95 bcm/year.

The China National Petroleum Corporation (CNPC) is also expanding expand capacity at the Bagtyyarlyk A block in the Lebap region to 8.0 bcm per year of sour gas. The gas field was discovered in 2012 and is being developed by CNPC in conjunction with Turkmengas to feed the Central Asian Gas Pipeline.

Iran

Finally, while it has concentrated on developing its giant South Pars field in the Gulf, Iran has also begun to look towards the Caspian Sea, now that an easing of sanctions has made cooperation with foreign oil and gas development companies slightly easier. In 2002, Iran discovered a gas field 700 m down off the coast of the northern Gilan province called Sardar-e Jangal. The field contains total proven reserves of around 50 tcf of natural gas and 500 million barrels of cride, but its deep water situation will require advanced drilling rigs which are in short supply in northern Iran. The National Iranian Oil Company's subsidiary Khazar Exploration and Production Company (KEPCO), in charge of developing the area, is said to be in continuing discussions with neighbouring Azerbaijan, as well as BP and Statoil, over the field, although the Trump administration's position on Iranian sanctions remains a potential cloud over any future collaboration, and so far matters are still at an early stage.

Sulphur demand

So far, then, the main regional sources of sulphur remain Russia, with 5.5 million t/a of production in 2016, mostly from sour gas and condensate processing at Orenburg and Astrakham and Kazakhstan, where TCO has up to 2.4 million t/a of output. Kashagan, once fully on-stream, perhaps later this year, will add 1.1 mil-

Contents

SULPHUR
ISSUE 372
SEPTEMBER-OCTOBER 2017

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lion t/a at capacity, and Galkynysh in Turkmenistan a further 1.8 million t/a. Some regional refineries and some gas processing in Uzbekistan also add some additional volumes of sulphur.

Set against this potential 11 million t/a or so of sulphur, regional demand remains relatively limited. At the moment there is phosphate processing in southern Russia, mainly PhosAgro, including its subsidiaries Ammophos and Balakovsk, and some industrial sulphuric acid plants which together consume between 2.5 million t/a of sulphur for sulphuric acid manufacture, and these are generally supplied from the Orenburg and to a lesser extent Astrakhan gas plants.

A growing use has been uranium mining in Kazakhstan. Kazakhstan is the largest producer of uranium oxide, U_3O_8, and it extracts this via sulphuric acid leach of relatively alkaline carbonate rocks, which consumes large volumes of acid (up to 70-80 tonnes acid per tonne uranium). Kazakhstan's uranium output has increased dramatically from just a couple of thousand tonnes in 2002-3 to 24,500 tonnes U_3O_8 in 2016, gaining the country a 40% share of the world's total uranium oxide output, according to the World Nuclear Association, and production of this amount of uranium consumes about 1.5 million t/a of sulphuric acid. Some of this acid comes from smelter off-gases; there is a 1.2 million t/a acid plant at the Kazakhmys copper smelter, and a 320,000 t/a acid plant at KazZinc at Ust-Kamenogorsk, although output is variable. However, there are also two sulphur-burning acid plants; a 500,000 t/a capacity plant was built by Kazatomprom at Zhanakirgan in 2011 which burns 170,000 t/a of sulphur at capacity, mainly from TCO, and a 180,000 t/a plant was built at Stepnogorsk in 2015. Another 180,000 t/a sulphur burning acid plant is being built at the Pavlodar refinery, fed by 60,000 t/a of sulphur from the refinery itself, and is due for completion this year.

Kazakhstan also has phosphate deposits, and Russian fertilizer producer EuroChem has a mine in the Jambyl region which began production in 2014, and which had ramped up to its initial capacity of 640,000 t/a by 2016. EuroChem is now planning to expand production to 1.5 million t/a, and advancing plans for a downstream 1.0 million t/a potassium sulphate and dicalcium phosphate fertilizer plant, which will consume up to 1.0 million t/a of sulphuric acid. Sunkar Resources is also developing the Chilisai Phosphate Project in Kazakhstan, but progress has been much slower there.

In Turkmenistan, a 500,000 t/a sulphur-burning acid plant was commissioned in 2016 at the Turkmenabat chemical complex. The acid is mainly destined for phosphate fertilizer production, with the sulphur supply coming from Galkynysh. Uzbekistan has 500,000 t/a of smelter acid capacity, at Navoi, and a similar sized sulphur burning plant operated by Ammofos-Maxam (a joint venture with Spain's Maxam) near Almalyk, 60 km from Tashkent. These ageing facilities are both being replaced by more modern, 650,000 t/a acid plants, with completion dates of 2018 and 2019 respectively.

All told, sulphur consumption in Kazakhstan, Turkmenistan and Uzbekistan amounts to only around 600,000 t/a. Added to regional Russian consumption, this leaves a large and growing surplus of sulphur of nearly 7 million t/a in the Caspian and surrounding region.

Difficult logistics

The Caspian Sea's land-locked nature makes exports from the region challenging. The 'sea' is really a large lake, and so railways must connect the production areas to ports or inland customers. The distances are extremely challenging - Kazakhstan alone is 3,000 km across, and rail transit times to e.g., China can be nearly two weeks. Seasonal weather conditions are just as wide-ranging. The northern Caspian Sea freezes in the winter for several months, while in the summer, oil workers need to cope with desert-like conditions. These climatic fluctuations have to be taken into account when constructing facilities. For instance, the $1.4 billion Yuri Korchagina field development has required the use of ice-resistant platforms – one for the drilling itself, the other for personnel – equipped with a helicopter deck.

At the moment, sulphur from Astrakhan is shipped by rail in two main directions, north and south. The former involves a 2,590 km journey from source to the port of Ust-Luga and the latter involves several routes: by road to the Buzan river port in the Astrakhan region and onwards by river-sea barges to export destinations or to the port of Kavkaz, where it is transferred to dry cargo ships. Sulphur is also shipped 900 km by rail to the Ust-Donetsk river port in the Rostov region, where it is loaded onto barges and taken along the Volga-Don canal to Kavkaz. It is also shipped by train to the Ukrainian Black Sea ports of Mikolayiv and Ilichevsk (1,600-1,950 km) and then loaded onto dry cargo ships for export. But barge export by river is only possible from April to November because of winter weather conditions. Much of the rail transit within Russia is done as liquid sulphur in rail tank cars, but a number of obsolete tank cars are due to be phased out of service in 2019, after which rail transport of liquid sulphur is expected to be minimised.

Storage or reinjection?

So given that the region is producing more sulphur than it can consume, and this situation looks set to worsen with the addition of Kashagan and expansions at Galkynysh and other sour gas processing sites, what will become of this sulphur? The difficulties in export mentioned above make finding customers in an oversupplied sulphur market all the more challenging. Russia nevertheless exported 3.8 million t/a of sulphur in 2016, 83% of which came from Astrakhan, with OCP in Morocco the major customer/destination. Russia's sulphur export set-up and markets are of fairly long standing, and the only incremental sulphur expected over the next few years, aside from the novel Norilsk metallurgical off-gas to sulphur project, is likely to come from new refinery capacity. Russia is looking towards alternative uses for sulphur, with Gazprom experimenting with sulphur bitumen and concrete, but the capability of these uses to absorb large volumes of sulphur remains very much open to question.

Kazakhstan, Turkmenistan and Uzbekistan, meanwhile, are all likely to be producing additional volumes of sulphur in the medium term – around 1.2 million t/a in Kazakhstan, 750,000 t/a in Turkmenistan, and 200,000 t/a in Uzbekistan by 2021. Kazakhstan has had issues with large scale block storage in the past, and although it is now looking into what may be long term, acceptable solutions, it currently plans to try and sell its sulphur no matter what. However, Kazakhstan's favoured solution is to move to more acid or sour gas reinjection to enhance oil recovery. Even so, the likelihood seems to be that these three states will be forced to store more sulphur over the coming years, as it will be difficult for exports from the Caspian Sea to compete with the flood of new exports from places such as Abu Dhabi unless producers are willing to accept extremely low sulphur prices. ■

SULPHUR
ISSUE 372
SEPTEMBER-OCTOBER 2017

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North American refining

US refiners are now some of the largest exporters of finished products, but changing feedstock slates, Canadian oil sands production, a revival of Mexican capacity and the prospects of US oil exports as well as the global demand situation may all have a bearing on future North American refined sulphur output.

The US oil and petrochemical industry continues to be transformed as a result of the tight oil boom, but the way that this has played out over the past couple of years has changed for a variety of reasons. One significant factor has been the fall in oil prices that began at the end of 2014. Prices for West Texas Intermediate (WTI) fell from around $80/bbl in October 2014 to $40/bbl at the start of 2016. This was mainly due to a global glut of supply, and Saudi Arabia's refusal to play its usual role of swing producer, continuing pumping its own oil in an effort to try and shut off tight oil production in the US and oil sands production in Canada. The breakdown of OPEC price discipline, coupled with new supply from Iran, Russia, Canadian oil sands and new US oil forced prices lower, and to some extent this had the effect that the Saudis had desired; US oil production peaked in early 2015, but thereafter fell back from its 40-year high of 9.5 million bbl/d to around 8.5 million bbl/d in late 2016.

Since then global oil prices rebounded slightly from their dramatic fall and WTI – which tends to trade at a slight discount to global markets anyway – has averaged around $50/bbl since mid-2016, with the re-imposition of some price discipline and production quotas by OPEC, joined by some major non-OPEC producers like Russia. This in turn has seen a supply side response from the US oil industry, and production has climbed steadily during 2017, reaching around 9.4 million bbl/d, only slightly below the peak figure in 2014. At time of writing, the fallout from Hurricane Harvey is difficult to judge, but the shutdown of much of the Gulf Coast's refining capacity has led to a temporary slump in US oil demand and a fall in pricing.

Nevertheless, while the slump in oil prices may have temporarily dented the rapid expansion of US tight/'shale' oil production, it has been only a blip in an otherwise meteoric rise. During the first six months of 2017, tight oil production, particularly from the Andarko shale in Oklahoma and Texas, where drilling costs are low, and the Permian Basin in New Mexico, as well as other regions like the Bakken and Eagle Ford shales has grown at a collective rate of over 100,000 bbl/d each month, and total tight oil production is now over 6.5 million bbl/d, dwarfing conventional production from e.g. deep water wells in the Gulf of Mexico.

> **"The rise in tight oil production has changed the dynamics of US oil supply.**

The rise in tight oil production has changed the dynamics of US oil supply, bringing a lot of light, sweet crude to the market. This in fact has not been an unalloyed benefit for US refiners, which had been gradually converting to accept more heavy, sour crude from Canada and the Middle East, and while US light sweet crude (often supplemented by natural gas liquids (NGLs) from condensate from natural gas fracking) had been relatively cheap, this was often because there was too much for US refineries to deal with without blending it with heavier feedstocks in order to meet the required crude slate, and because US laws dating back to the oil crisis of the 1970s prevented the international export of crude.

Imports and exports

A safety valve for this has been the easing of restrictions on US oil exports. The ban was lifted in January 2016, and since then the US has become a growing imported of oil. In 2016, the US exported an average of 520,000 bbl/d of crude, mainly (58%) destined for Canada, with Europe, China and Curacao other large takers. At the same time, however, the US remains a large importer of foreign crude, and indeed US imports of crude from overseas have also increased in the past couple of years following a decline due to substitution from tight oil. The increase in imports has been in order to meet increasing demand at refineries and to help those refineries balance their inputs. US oil inputs had been on a declining trend from about 2006 as increasing domestic production gradually displaced the need to import oil – mainly from Canada, Mexico, Venezuela and Saudi Arabia. However, in 2015 imports increased slightly, and in 2016 dramatically, by a net 460,000 bl/d even taking into account the increase in exports, due to increased refining activity.

The source of these imports has also changed. Venezuela's share has dropped to 9% of imports, due to increasing restrictions on trade between the US and Venezuela, and to an extent the country's decaying oil infrastructure and domestic political issues. Mexico's share has also fallen as domestic demand increases there, and now stands at only 7% of US oil imports. On the other hand, imports of Canadian crude have increased dramatically, and now reach 3.2 million bbl/d in 2016. Iraq and Nigeria are also supplying more oil to the US now. Canada and Mexico are important as sources of both supply and demand for finished products for the US petrochemical because of another restrictive law – the Jones Act – which requires shipping of cargo between US ports to be carried on US built and flagged vessels, putting limits on the way that foreign oil can be moved around the country, and tending to support imports of crude over land, from Mexico and Canada.

Lifting the ban on US oil exports could be a mixed blessing for the US refining industry. In the past, the ban had meant that a surrogate export market had developed via finished products. It has also helped to close the gap between WTI prices and the international Brent Crude benchmark. In the past this gas has been a discount of up to $12/bbl for WTI, but that now runs at only $2-4/bbl, making US refinery inputs that much more expensive.

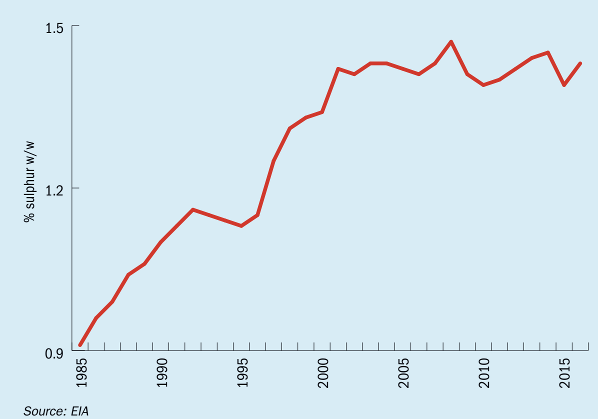
Refining

While the fall in oil prices has hit domestic crude output, it has not had any noticeable impact on US refinery output, which has run at record levels this summer, with refinery runs averaging over 17.6 million bbl/d. This record run has come in spite of a dip in domestic demand for refined products, and in addition to increasing stockpiles has also pushed more refined products onto the international market. US exports of refined products have continued to increase, reaching 1.2 million bbl/d of distillate and just under 800,000 bbl/d of gasoline in 2016. Mexico is the largest destination for exports, with other Central and South American countries also large markets. Exports of distillate have risen by 80% since 2010.

US refinery capacity has continued to incrementally increase over the past 25 years, mainly due to piecemeal improvements at existing sites, although this followed a long slump after a peak in about 1980, and it is only in the past couple of years that US refining capacity has increased beyond that previous peak from 35-40 years ago. The difficulty in securing approvals for new refineries in the US means that existing capacity tends to be worked quite hard, and utilisation rates have not fallen below 90% for some time.

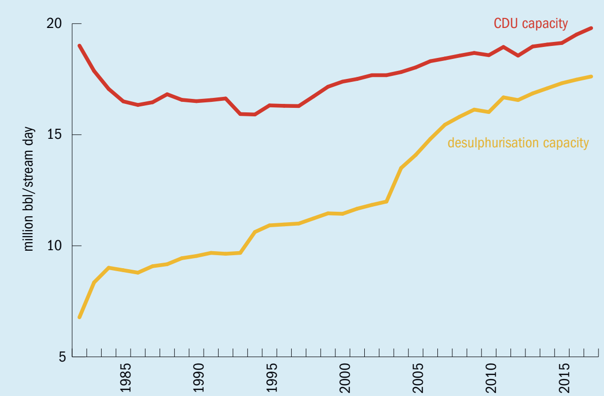
The geographical distribution of refining capacity remains relatively constant. The US refining industry is divided into

Fig 1: **Average sulphur content of inputs to US refineries, % w/w**



Source: EIA

Fig 2: **Desulphurisation capacity of US refineries, million bbl/stream day**



Source: EIA

Table 1: **Breakdown of US refining capacity, 2017**

District	No. refineries	Total capacity (million bbl/d)	Desulphurisation capacity (million bbl/d)
PADD 1	9	1.35	1.03
PADD 2	27	4.28	3.91
PADD 3	58	10.34	9.34
PADD 4	16	0.73	0.59
PADD 5	31	3.09	2.69
Total	**141**	**19.80**	**17.62**

Source: EIA

SULPHUR
ISSUE 372
SEPTEMBER-OCTOBER 2017
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five so-called Petroleum Administration for Defence Districts (PADDs), a classification going back to the Second World War when gasoline was rationed. Broadly speaking, PADD 1 covers the East Coast states, PADD 2 the Mid-West, PADD 3 the US Gulf Coast (USGC) states, PADD 4 the Rocky Mountain states, and PADD 5 the East Coast. Since the US refining industry was set up to process imported crudes, most of the refineries are on the east, west and southern coasts, especially the US Gulf Coast (PADD 3). However, the tight oil boom has come mainly from the Mid-West (especially the Bakken shale) as well as from Canadian syncrude, and athough there has been much investment in new pipeline capacity to carry these new supplies (including natural gas liquids pipelines from the shale gas regions), pipeline capacity has lagged behind increased supply, and environmental opposition has delayed major infrastructure works like the Keystone XL and Dakota Access pipelines. The Trump Administration revived some of these plans in its first few days, although they remain mired in legal challenges for now.

Tightening regulations

Regulations on sulphur content in fuels continue to tighten. The most recent change that all but the smallest refiners have had to deal with is the move to so-called 'Tier 3' gasoline standards, which specifies a maximum 10ppm of sulphur in gasoline from January 2017 (this is extended to 2020 for small refiners), down from the previous limit of 30ppm. The US Environmental Protection Agency (EPA) awards credits to refiners who produce gasoline with sulphur levels below regulated levels, and they may transfer credits from the existing Tier 2 program into the new one. Refiners can dip into their own pile of credits or buy them from their competitors to offset their production of higher-sulphur gasoline.

According to the EPA, of the 140 or so refineries currently operating in the USA, 108 will be impacted by the new regulations. Of these, 40 were either already meeting the new standards or would be able to buy credits to cover for the deficiency until operating changes (e.g. running on lower sulphur inputs) can be made. Another 64 have needed to revamp their existing hydrotreaters or add feed pre-treatment or gasoline post-treatment options, with a combined investment cost of $2 billion. Only one refinery would require an entirely new hydrotreater to comply, according to the EPA. The cost of compliance for refiners obviously has to be set against the alternative cost of buying sulphur credits, with a first tier of credits expiring in 2019 based on the original 30ppm standard, and purchasable before 2017, and those working off the 10ppm standard. However, unsurprisingly, the cost of sulphur credits rose as the deadline approached, from an average of $10-50/million ppm-gallons in 2014 to up to $350 in 2015.

In addition, new International Maritime Organisation (IMO) regulations on sulphur content of shipping fuels are also tightening and reducing the market for heavy sulphur fuel oil. From 1 January 2015, vessels traveling within the US Emissions Control Area (ECA) have been required to use fuels with less than 0.1% sulphur rather than the previous permitted 1%, but the next major step will come in 2020 with a global cap on sulphur content of fuels of 0.5%, down from the previous 3.5%. While ships may use add-on exhaust gas scrubbing systems to meet the new requirements, there is so far no sign of a large scale take up of such devices, and the best guess is that the new regulations will necessitate significant extra investment into producing more distillate and removing sulphur from bottom of the barrel fractions. The Catch-22 for refiners is that investment will only pay off once a significant differential between light and heavy product prices develops, after the 2020 deadline.

Changing crude slates

Refiners also continue to have to balance changing crude slates. The increase in availability of tight oil has been one reason for this; crude produced from tight oil shales averages around 0.2% sulphur by weight, compared to around 0.5% for WTI and 2% for Mexican Maya blend. However, as Figure 1 shows, while the average sulphur input into US refineries has risen steadily from the 1980s to the early 2000s, as refiners sought to convert their operation to be able to handle cheaper, sourer crudes, for which there was an increasing price discount as refiners worldwide tried to use sweet crudes to meet tightening sulphur relations, in fact since the first few years of the 21st century sulphur inputs have not changed drastically. This is because the investments in desulphurisation capacity have already been made and indeed continue to be made due to the tightening sulphur regulations mentioned above. This means that in spite of the new supply of lighter, sweeter tight oil, heavy, sour crudes from Mexico, Venezuela and Saudi Arabia have been coming into the US to balance this as refinery inputs. But this continues to be a moving target. For example, in recent months, OPEC production cuts have reduced the supply of medium and heavy quality crude oil to the world market at the same time that production outages in Canada and declines in production from Mexico and Venezuela have further reduced the total amount of medium and heavy crude oil available to refiners. On the other hand, the overall long-term increase in imports of Canadian bitumen is continuing, especially into the PADD2 region.

Sulphur output

So where does that leave US sulphur production? Figure 2 shows how desulphurisation capacity has steadily increased over the past 25 years, roughly tripling during that time, at the same time that overall crude distillation capacity has stayed relatively constant. This seems to be a trend likely to continue, as the global oil supply continues to move towards heavier, sourer crudes. Table 1 shows the regional distribution of this desulphurisation capacity – most of it continues to reside in the Gulf Coast region in PADD3, which is able to import crudes from all over the world and export finished products where there is an excess over domestic demand.

US elemental sulphur production in 2016 was 9.1 million metric tonnes, according to the US Geological Survey, up about 3% on 2015. Of this figure, oil refining accounts for around 8.1 million t/a, and Louisiana and Texas accounted for about 52% of overall sulphur production, with 63% being recovered in the PADD3 region. The outlook for the next five years is relatively stable – around 8.1 to 8.3 million t/a of total sulphur output from refineries, but even though the overall sulphur balance to refineries in terms of crude slate continues to stay fairly constant, continuing investment in desulphurisation capacity due to the Tier 3 gasoline requirements and the upcoming IMO regulation changes may see production nevertheless increase incrementally over the coming few years.

SULPHUR
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SEPTEMBER-OCTOBER 2017

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Licence to operate

PHOTO: TSI

Craig Jorgenson, vice president for Transportation and Regulatory Affairs at The Sulphur Institute, discusses the importance of transport and handling regulations to the sulphur industry's 'licence to operate'.

PHOTO: TSI

Main pic: Bulk transport of sulphur.
Above: Sulphur loading into rail hopper car.

Continuous sulphur offtake is paramount to sustained gas and oil processing operations at refineries and plants throughout the world. Just as important is a predictable influx of sulphur as a raw material at consumption facilities such as fertilizer manufacturing plants and sulphuric acid regeneration plants. A critical component supporting offtake and receipt of sulphur is uninterrupted and cost effective transportation and handling in various forms within supply chains. While forming facilities, ports, trucks, rail cars, barges and ships are critical elements of the distribution network, an understanding of the regulations that underpin road, rail and marine transportation of sulphur, in all forms, is essential for the sulphur industry professional, providing them with a 'license to operate.'

For over 25 years, The Sulphur Institute has been influential in helping create and sustain regulations around the globe by providing various international and regional regulatory bodies with information about the characteristics of sulphur in all forms. Not only has this sharing of information helped shape transportation regulations, it has also helped open doors to previously untapped markets.

An understanding of how dangerous goods regulations are promulgated provides shippers and carriers alike a foundation from which to start. This work starts at the United Nations (UN) level. The UN Economic and Social Council (ECOSOC) Committee of Experts on the Transport of Dangerous Goods (TDG) coordinates the regulations for transportation of dangerous goods. This committee consists of 30 delegates from UN member countries and they produce the "Recommendations on the Transport of Dangerous Goods", commonly referred to as the 'Orange Book'. The Orange Book lists handling requirements for thousands of chemicals categorised into nine separate hazard classes. These chemicals each receive a unique UN number. In the case of sulphur, two UN numbers are assigned under its flammable solid classification; UN1350 for solid sulphur and UN 2448 for sulphur in molten state. Both of these are found in the Dangerous Goods List in the Orange Book. Shippers and carriers familiar with the Dangerous Goods List understand the requirements for packaging and handling of the product, they also understand any special provisions allowed during transportation of the product. In the case of solid sulphur (UN1350) a special provision applies when the product is formed into a specific shape such as prills, granules, pellets, pastilles or flakes. The Special Provision 242 (SP 242), which dates back to 1992, specifically states that sulphur is not subject to the dangerous goods regulations when formed into the specific shapes mentioned above.

The adoption of SP 242 was not a rushed decision by the TDG Committee. From 1985-1992, TSI staff along with sulphur industry stakeholders made great efforts in two areas to help inform the committee of sulphur properties. Improved technologies in the various forming processes led to significant reduction in the friability of formed solid sulphur. This was followed by laboratory testing of formed solid sulphur using UN approved testing methods to demonstrate when sulphur is formed into a specific shape, the risks commonly associated with a flammable solid are significantly mitigated. The combination of improved technologies and the test results were the two significant factors in adoption of SP 242 by the TDG.

Member states of the United Nations and other UN bodies, such as the International Maritime Organisation (IMO) use the Orange Book recommendations as the foundation to codify regional, national or mode specific regulations. These recommendations may be adopted verbatim into regulations or may be used to help shape regulations used by national or regional enforcement agencies. Member states can also choose not to adopt the recommendations. In the case of formed, solid sulphur (UN1350), the elements of SP 242 are recognized and adopted in several regulations throughout the world. (See table below for examples). Special Provision 242 also played a significant role recognizing formed, solid sulphur as a special paragraph in the IMO's International Maritime Solid Bulk Cargoes (IMSBC) Code, providing for no special handling or significant ship alterations for carrying the product in bulk in marine vessels.

Table 1: Adoption of SP242 provisions in selected states

Region/country	Regulation	Adopted
European Union	ADR*	Yes, as SP242
United States	49 CFR**	Yes, as SP30
Canada	TDR***	Yes, as SP33

** European Agreement concerning the International Carriage of Dangerous Goods by Road*
*** 49 Combined Federal Regulation, Transportation*
**** Transportation of Dangerous Goods, Clear Language*

Special Provision 242 has helped influence other regulatory actions as well such as proving sulphur as non-hazardous to the marine environment (non-HME) under International Convention for the Prevention of Pollution from Ships (MARPOL) Annex V and aiding the European Maritime Safety Agency (EMSA) in preparing pollution response guidelines for their Marine Chemical Information Sheets (MAR-CIS) on sulphur.

The adoption of Special Provision 242 recognizes lower risk in the transportation of formed, solid sulphur, eliminating the need for special equipment, special transport routing, train car placement or insurance, saving an untold amount of money for shippers and carriers over the last 25 years. Sulphur industry professionals should have an understanding of how the United Nations Recommendation for Transportation of Dangerous Goods applies to the movement of all sulphur products in their country or region. This 'license to operate' can lead to cost savings throughout the industry supply chain, but perhaps more importantly, protect workers, equipment and the environment during the safe transportation of sulphur. ■

SULPHUR
ISSUE 372
SEPTEMBER-OCTOBER 2017

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The potential for sour gas development

As recovered sulphur from sour gas continues to boost the global sulphur supply, how much more sour gas remains unexploited?

Last issue (*Sulphur* 371, Jul/Aug 2017) we looked at the current state of development of various sour gas projects around the world, which are continuing to increase the levels of recovered sulphur, especially in places such as China, Central Asia and the Arabian Gulf. The trend towards more sour gas recovery has accelerated over recent years and decades as gas has become a preferred fuel for power generation in fast growing, industrialising regions, and sweet gas has come to be in more and more restricted supply. It is however worth noting that the North American shale gas boom has very much changed the equation for the United States and Canada, with abundant, relatively sweet shale gas displacing more expensive sour gas. The potential still exists for this to happen elsewhere, and considerable effort has been made in China to tap into shale gas reserves, but at the moment there is no convincing sign of anything comparable to the North American experience elsewhere.

> Just over 40% of the world's natural gas reserves are classified as sour.

Tentative European attempts to develop shale resources have been stymied by environmental opposition and more complex geology.

So, given the impact that sour gas has already had on global sulphur production, is there the potential for more large volumes of sulphur being produced from additional sour gas exploitation? The first step in deciding this is to look at where those reserves are. Table 1 shows estimates of sour gas availability compiled by the International Energy Authority (IEA), excluding North America (where prospects for more sour gas look remote at present)[1]. As can be seen, something approaching just over 40% of the world's natural gas reserves are classified as sour, and even if fields which have high CO_2 but not hydrogen sulphide are discounted from the picture, this still leaves 33% with more than 100ppm H_2S. By way of comparison, the comparable figure for North America suggests that sour gas makes up just over 20% of remaining reserves. In terms of absolute numbers, 55.8 tcm of gas in Table 1 has more than 100 ppm hydrogen sulphide, representing about one third of all global gas reserves, and 77% of this is in the Middle East. About 0.97 tcm of this gas is highly sour, with an H_2S content in excess of 10%[2].

The regional figures show that the greatest concentrations of H_2S by far lie in the Middle East, with the FSU (mainly around the Caspian Sea area – discussed elsewhere this issue) and to a lesser extent Asia Pacific (mainly representing the sour gas rich fields of southern China). While it may not come as too much of a surprise that the established areas which produce large volumes of sour gas and sour gas-derived sulphur are thus also the ones with the most potential for new development, the Caspian and the Middle East are clearly the ones where there is most H_2S-rich gas still to be exploited.

Acid gas reinjection

As we note in our article on pages 22-26, one way of avoiding the inconvenience of having to process and extract large tonnages of sulphur from sour gas is to reinject sour or acid gas into oil wells for enhanced oil recovery, and many new field developments in the Caspian region are looking towards this. During the end of the last decade, a survey was made of all high CO_2 reservoirs (most of which are also high H_2S reservoirs), for the purposes of determining the feasibility of using carbon dioxide for enhanced oil recovery (EOR) as well as carbon capture and storage (CCS)[3]. This, broadly speaking identified five major regions where there were large volumes of sour gas available; North America, North Africa, the Middle East, the Caspian Sea area, and southeast Asia/offshore northern Australia. Discounting those fields which are high in CO_2 but relatively low in H_2S (such as Natuna in Indonesia, which has over 70% CO_2 but very little $H2_S$), this leaves the Middle East, Caspian and North America, all of which could benefit from enhanced recovery from existing oil fields by reinjection of sour or acid gas. The difference between them lies in their relative needs for natural gas for other purposes. North America, as discussed, now has relatively abundant gas supplies, and approximately 'breaks even' in terms of production and consumption. The Caspian is a net gas-exporting region by some margin, and so may be more likely to choose to reinject more gas to generate more oil. However, aside from the huge LNG exporting hub of Qatar, the Middle East has become more and more in need of natural gas to fuel power generation and industrial development, and so is the most likely region to extract and process the gas rather than reinject it.

The new sulphur boom?

All of this taken together – possession of over three quarters of all remaining high-H_2S gas reserves; and a need for more gas to fuel power generation, especially to run air conditioning as the world continues to warm, would seem to indicate that the Middle East is the place to watch for more sulphur extraction. The rapid development of Abu Dhabi's sour gas reserves and consequent huge volumes of sulphur exports may be the way of the future, as Saudi Arabia, Kuwait, Iran, Qatar and Oman all follow suit.

There is one potential downside risk, and that is the development of shale gas resources as an alternative. Saudi Arabia in particular seems to have changed course on this, and this year will begin its first shale gas production at Al Jalamid. Next year it plans to be producing 5.6 million cubic metres per day, sending it to the new phosphate complex and mining city at Waad al Shamal in the northern desert. But the country has ambitious plans to scale this up to 113 million m³/d (4 bcf/d) by 2026, and Ali al-Naimi, the Saudi Minister of Petroleum and Mineral Resources, says that the kingdom possesses about 600 tcf of shale gas reserves, which would put Saudi Arabia fifth in the world in terms of unconventional gas reserves. There remain many questions over this, not least of which is the availability of water for fracking operations which, needless to say, is in short supply in the Kingdom. However, if it does succeed it could put a cap on sour gas extraction and change the dynamics of the sulphur industry once again.

References

1. International Energy Agency, World Energy Outlook.
2. F. Lallemand et al, Sour gas production: moving from conventional to advanced environmentally friendly schemes, SOGAT Conference, Abu-Dhabi, 29 Apr-3 May 2007.
3. W.F.J. Burgers et al, Worldwide development potential for sour gas, *Energy Procedia 4* (2011), 2178-2184.

Table 1: **World proven sour gas reserves (outside North America), trillion cubic metres**

	High H_2S^1	High CO_2^2	High CO_2+H_2S	Total	% of all reserves
S/Central America	0.3	1.1	0.3	1.7	21
Europe	0.1	0.7	0.3	1.1	19
FSU	0.8	10.1	7.3	18.2	34
Africa	0	0.5	0.5	1.0	8
Middle East	2.6	0.4	40.9	44.0	60
Asia-Pacific	0.3	4.4	2.3	7.1	46
World	**4.2**	**17.2**	**51.6**	**73.1**	**43**

Notes: 1. >100ppm H_2S 2. >2% CO_2 *Source: IEA*

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Sulphur 2017 meets in Atlanta

Now in its 33rd year, Sulphur 2017, CRU's premier industry event for the sulphur and sulphuric acid industries, will take place on 6-9 November 2017 at the Hilton Atlanta hotel in Atlanta USA. In this preview we highlight the events and some of the key topics in this year's programme.

Regularly attracting over 550 delegates from around the globe, representing sulphur and sulphuric acid producers, operators, consumers, technology and engineering suppliers and service providers from across a range of industries, the Sulphur Conference and its exhibition of 60+ exhibitors offers the opportunity to meet, learn and network. The extensive programme includes pre-conference workshops, commercial sessions covering key market trends, project updates and supply and demand forecasts and a two-day split stream technical programme showcasing the latest technological developments.

Attendees at Sulphur 2017 can expect to learn about new projects, hear first hand about new technologies, learn from others operational experiences, and benefit from interactive workshops led by industry experts.

Pre-conference workshops

MONDAY 6 NOVEMBER

Optimized Gas Treating will be hosting a hands-on **Sulphur Recovery Workshop** using process simulation software and covering the following topics:

- Thermal reaction: contaminant destruction (NH_3, BTEX, hydrocarbons); the evil step cousins – CS_2, COS, and trace sulphur; oxygen enrichment; waste heat boiler recombination reactions and heat flux implications.
- Sulphur condensers: equipment design and rating; $H_2S/H_2SX/SO_2$ solubility; entrainment.
- Catalytic conversion: optimal operating temperature; catalyst selection; COS/CS_2 conversion vs Claus reaction; modelling SOR vs EOR conditions.
- Sulphur storage, handling, and degassing: sulphur viscosity, product quality, H_2S degassing.
- Tail gas clean-up: effect of NH_3 and SO_2 on quench column and amine system performance; EOR design and operation considerations.

SNC Lavalin will be hosting a sulphuric acid workshop on **Efficient Project Management** and will present an overview of the components of project management that play a significant role in the planning, execution, reporting, analysis and advancement of project objectives. They will discuss lessons learned throughout various industries and how the application of these lessons learned have resulted in systems that can assist in managing the common areas of project risk.

The objectives of this workshop are to:

- Provide practical insights to owners and project managers on state-of-the-art tools for managing risks and achieving successful projects.
- Assist in development of execution strategies.
- Understanding data analytics for decision making.

In addition, there will be a sulphuric acid workshop on **HAZOPs in Sulphuric Acid Plants** moderated by Rick Davis of Davis and Associates Consulting. This workshop will focus on various accepts of the process safety management and the HAZOP process as it applies to the sulphuric acid process and production. It will include the scientific methodology and the regulatory obligations, and look into several sulphuric acid incidents that were not addressed by these reviews.

The session will include presentations that will be geared towards practicing engineers with various degrees of exposure to the sulphuric acid process, plant operation, and plant maintenance. Following the presentations, there will be a panel discussion providing participants with the opportunity to have their questions answered by a panel of industry experts including Jim Doherty of The Mosaic Company and Leonard Friedman of Acid Engineering Consulting.

SULPHUR
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SULPHUR 2017 CONFERENCE PREVIEW

Commercial sessions

TUESDAY 7 NOVEMBER

The first day of the conference will comprise nine presentations covering market outlooks for oil and gas, sulphuric acid and phosphates; innovations in the oil, gas and chemical sectors; sulphur supply and demand; the North American acid landscape; the impact of the global sulphur cap on marine fuels; and the delivery approach for the Mosaic New Wales sulphur melting project.

The commercial sessions will close with an interactive panel discussion, which will reflect on the development of the sulphur and sulphuric acid industries over the past three decades, exploring how technology has developed to meet new emissions regulations; the overall global sulphur balance situation and subsequent impacts on the sulphuric acid market. The interactive panel discussion will be moderated by Angie Slavens of UniverSUL Consulting. Panelists include: Rob Marriott (ASRL), Randy Hauer (AMETEK Process Instruments), Doug Cicerone (Cicerone & Associates), Lon Stern (Consultant, Stern, Inc.), Paul Davis (ASRL), Michael Huffmaster (Consultant, Michael A. Huffmaster, PE, LLC), Jamie Swallow, President/CEO, (Sulphur Experts), Elmo Nasato (Nasato Consulting) and Gene Goar (Goar Sulfur Services & Assistance).

Technical programme

8-9 NOVEMBER

In the technical programme, sulphur and sulphuric acid streams will be run in parallel. There is a strong emphasis on papers based on case studies that address key operational areas including reliability, efficiency, OPEX reduction and productivity enhancements. Delegates can also benefit from the interactive troubleshooting clinics that are structured around an open format Q&A with a focus on maximum audience participation.

Following the success of the first sulphur recovery clinic in 2016 the **Sulphur Operations Troubleshooting Clinic** will be back in Sulphur 2017 and will be moderated by Elmo Nasato of Nasato consulting. Themes explored will include:

- Sulphur recovery
- Tail gas treating
- Sour water stripping
- Contaminant destruction
- Maintenance and reliability
- HSE strategies and best practice
- Sulphur handling

New for 2017, there will be a **Sulphuric Acid Operations Troubleshooting Clinic** moderated by Steve Puricelli of Sulphuric Solutions. This interactive session is designed to provide an open forum for delegates to discuss operational problems, share experiences and develop solutions. Themes explored will include:

Process response to equipment failures

- Drip acid
  - Determining the source of water
  - When to shut down
  - H_2 generation
- Opacity
  - Determining SO_3 slip vs mist
  - Likely causes
- Converter issues
  - High SO_2 emissions
  - Pressure drop build-up
  - Mechanical failures
- Other issues
  - Acid cooler leaks
  - Blower surging
  - Blocked mist eliminators
  - Sulphur sublimations

Presentation highlights

The technical programme covers a wide range of topics. Selected highlights of some of the presentations are outlined below.

Dow will be discussing **how to lower sulphur emissions from refinery tail gas systems using improved amine solvents.** Removal of residual hydrogen sulphide from low pressure sulphur plant tail gas has proved challenging at elevated lean amine or ambient temperatures. Dow's new series of speciality solvents, UCARSOL™ TGT, offers economically competitive alternatives for reducing sulphur emissions in high temperature environments. Field demonstration results will be presented from a gas treater operated by CNOOC Huizhou in Guangdong, China, where SO_2 emissions of less than 100 mg/Nm³ were achieved with no capital expense.

Gordon Finnie will be providing an **operator's guide to achieving and maintaining high sulphur plant availability**, based on his first hand experiences at a major oil company, where he was instrumental in increasing the availability of a system of 14 refineries with a combined Solomon Availability of 85% in 2002 to 93% by 2009. The use of benchmarking, inter-business help, defining standards for operations, projects and turnarounds, as well as making the journey to become a learning organisation were very important factors in both achieving and maintaining the performance level.

Amec Foster Wheeler will discuss the intricacies of **two-stage sour water stripping process control** based on a recent study of an existing two-stage sour water stripper in a US refinery. An on-going trend of increasing nitrogen content in crude oils leading to increased ammonia and sour water production has sparked interest in the two-stage sour water stripping process as a tool for managing the increasing levels of ammonia. The study also considered the use of the refinery's existing sulphur recovery unit for processing a concentrated ammonia stream from the second stripping a stage, as an option for operating the two-stage stripping unit during outages of the downstream ammonia product recovery system.

Sulphur Experts/Amine Experts will continue their Seven Deadly Sins series, this time focusing on the most common **design, operation and reliability problems encountered in tail gas treating units** that impact emissions compliance or reliability of the unit. Despite the maturity of the hydrogenation with amine absorber tail gas unit, some facilities do not operate the SRU and TGTU with a proper understanding of the fundamentals of the process integration and knock on effects of inadequate operation and maintenance of each process step.

Optimized Gas Treating will examine Claus waste heat boiler economics for several designs benchmarked in terms of:

- Reliability with corrosion and peak heat flux impacts on tube life;
- Claus unit hydrogen production and potential savings in TGU make-up hydrogen;
- boiler equipment cost;
- Claus unit combustion air blower power and SRU hydraulic capacity.

Quantitative behaviour of the WHB and how it subtly impacts SRU performance can be predicted using a newly developed rate-based heat transfer and chemical reaction model.

MPR Services will provide practical advice on preventing hydrocarbon carryover into the sulphur plant from the amine treater. Typical mitigation measures will be discussed including:

- Skimming the HC from the flash drum due to different densities;
- knockout drums installed upstream of the amine treater and upstream of the sulphur plant;
- activated carbon;
- use better separation techniques employed ahead of the amine plant;
- other novel ways for removing hydrocarbon in the amine plant.

ASRL will be providing a **better understanding of ammonia destruction in the Claus furnace**. Recently, ASRL have been focusing on ammonia destruction studies with full Claus feed streams at different SWS/AG ratios. The experimental results from both single zone and dual zone furnace experiments will be discussed. The data from these studies should be applicable for those who are involved in improving CFD modelling of new and existing furnaces/burners.

Haldor Topsoe will be launching its **new LEAP5™ catalysts for SO_2 oxidation**. New results from Topsoe's advanced in-situ studies will be presented as an example of how fundamental knowledge, such as the dynamics and chemistry of the active melt on the carrier, has led to the development of a new LEAP5™ catalyst, which has been optimised for higher activity at lower temperatures. The new catalyst has the potential to help acid plant operators to reduce operational cost, cope with new emission demands, improve productivity and avoid expensive capex projects.

Chemetics will be discussing **a new approach to acid plant design**, offering a different concept for both plant expansions and newly built plants based on the Chemetics CORE™ Isothermal Converter (previously BAYQIK®). Chemetics will review the benefits achieved by clients that have installed a CORE™ system in their sulphuric acid plant and will introduce the latest generation of the system which allows for higher conversion and plant capacity at a lower cost.

H_2SO_4.pm will be discussing major actions that can be taken to **improve the overall equipment effectiveness (OEE) in your sulphuric acid plant**. Availability losses (planned and unplanned stops), performance losses (small stops and slow cycles) and quality losses (process defects and reduced yield) will be examined.

BASF will share **new developments in the geometry of BASF sulphuric acid catalysts**, the Quattro. Attendees will have the chance to see lab results compared to a recent commercial trial at a sulphur burning plant in Europe. The encouraging results show the impact of catalyst geometry on catalyst performance.

Cansolv Technologies will discuss a case study for a sulphuric acid production site at a fertilizer plant in Louisiana, comparing real operating date from a **Cansolv unit treating tail gas from a single absorption plant versus a conventional double absorption acid plant** on the same site. The comparison highlights the advantages of applying regenerable tail gas solutions and the benefits it brings to an existing operation.

thyssenkrupp Industrial Solutions (tkIS) will explore **what blast furnace coke and modern sulphuric acid plants have in common**. Many new solutions to improve heat recovery and reduce emissions in sulphuric acid plant have been derived from coke plant technology. In the last two years tkIS has developed new sulphur burning sulphuric acid technology, influenced by the design criteria of coke plants: the plant is operated 24/7 and 365 days a year and high environmental standards have to be strictly followed. The tkIS technology not only ensures an emission-free start-up of a sulphuric acid plant but also maximises the heat recovery of the plant.

MECS will be introducing its **next generation of sulphuric acid technology**. MAX3™ is a proprietary sulphuric acid technology that simplifies the conventional sulphuric acid plant flow scheme by combining a single absorption HRS™ plant with MECS' SolvR® regenerative scrubbing technology to eliminate equipment, cut costs and increase efficiency. In a MAX3™ plant, the use of SolvR® makes it possible to achieve close to zero SO_2 emissions.

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Innovative wet ESP designs

PHOTO: SOUTHERN ENVIRONMENTAL

Modern gas cleaning and emission control strategies continue to evolve in response to the increasing complexity, toxicity and corrosiveness of industrial exhaust and process gases, not to mention increasingly stringent environmental regulations. In this article we track the commercial progress made during the last decades in the development of high performance wet electrostatic precipitator solutions to replace aging wet ESP models with all-lead internals.

Metallurgical sulphuric acid plants are commonplace in non-ferrous metallurgical operations, providing a means of recovering sulphuric acid and preventing sulphur dioxide (SO_2) emissions. In non-metallurgical applications, such as petroleum refining where sulphuric acid is utilised as a catalyst, regenerating spent sulphuric acid is also common. In both of these applications, wet electrostatic precipitators (wet ESPs) are an important step in ensuring high-efficiency reduction of dust, fume, and sulphuric acid mist in order to optimise sulphuric acid quality.

In non-ferrous metals plants, materials such as molybdenum, copper, zinc, nickel and lead are separated from the ore through a roasting or smelting process. Off gases from the roasting of ore in these smelters are laden with particulates, metal oxide fumes, as well as sulphuric acid vapour. Before the off gas can be sent to the sulphuric acid plant it must be cleaned and concentrated in a gas cleaning plant to produce a clean SO_2 rich gas.

Sulphuric acid plant owners have employed several gas cleaning techniques, including wet or dry scrubbers, cyclones and fabric filters. These systems can capture larger particulates, but are usually energy-inefficient or impractical to use on fine particulates, acid mists, oily residues, or condensed organic compounds. Many plant operators thus find that the best solution for removing these contaminants is a modern adaptation of a traditional technology: the electrostatic precipitator, or wet electrostatic precipitator (wet ESP) which features intermittent or continuous washing of the particulate matter to the collection area of the system.

Impurities can vary greatly from one plant to the next, depending on the ore composition. Table 1 shows the key impurities typically encountered in the gas stream entering the sulphuric acid plant and Table 2 shows some typical contaminant limits for sulphuric acid quality requirements in modern plants.

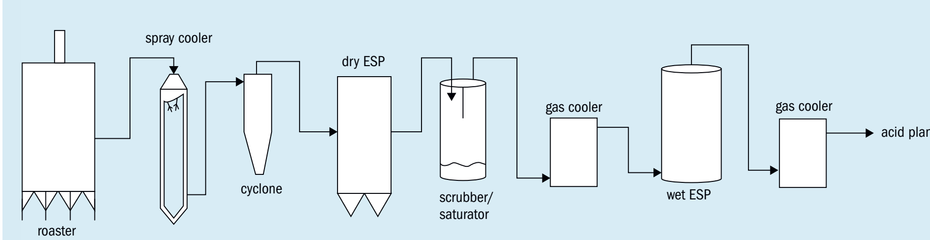
Table 1: **Key impurities to be treated in a gas cleaning plant**

Aerosol/particulate laden	Gaseous
Lead (Pb)	Mercury (Hg)
Arsenic (As)	Hydrochloric Acid (HCl)
Selenium (Se)	Hydrofluoric Acid (HF)
Mercury (Hg)	Selenium (Se)

Table 2: **Typical sulphuric acid product quality contaminant limits**

Hg: 0.5 ppm
As: 0.5 ppm
Se: 0.5 ppm
Pb: 1.0 ppm

Fig 1: **Typical gas cleaning system**



Source: Southern Environmental

An efficient sulphuric acid manufacturing process requires the maximum possible removal from input gas streams of fine particulates, acid mists, condensable organic compounds and other contaminants. This high level of gas-cleaning efficiency is necessary to prevent poisoning of the catalysts and fouling or plugging of the catalyst beds. An optically pure input gas is essential for avoiding the formation of a "black" or contaminated acid end-product. Proper gas cleaning also helps protect sensitive acid plant components against corrosion damage, thus lowering long-term expenditures for maintenance and equipment replacement. Ultimately, cleaner gas streams facilitate the production of stronger concentrations of sulphuric acid, suitable for a wider range of end-uses.

Several design factors must be considered in the gas cleaning plant including:

- sizing of dry electrostatic precipitators (dry ESPs) for dust collection;
- achieving proper process gas saturation;
- designing the wet acid gas and particulate scrubbers for removal of acid gases such as hydrochloric and hydrofluoric acids, along with super-micron fractions of metallic fumes;
- sizing of highly efficient wet ESPs to reduce sulphuric acid mist, fine particulates, and fumes of heavy metals to the necessary levels required to achieve the desired acid quality.

Vapour phase mercury control is typically controlled after the wet ESP system.

Fig. 1 shows a conceptual process flow chart for a typical gas cleaning system.

All of the components have to function in harmony to ensure maximum SO_2 removal efficiency. The spray cooler cools the off-gas to approximately 315°C. The cyclone and the dry ESP are used to capture solid particulate and recover raw material which is usually recycled back to the roaster for further recovery. The saturator and the gas cooler saturate and sub-cool the off-gas removing moisture. During this saturation and sub-cooling process, SO_3 vapour is converted into H_2SO_4 mist. The wet ESP captures the H_2SO_4 mist and the second stage gas cooler further sub-cools the gas. It is important that H_2SO_4 mist is removed from the off-gas to prevent corrosion in the downstream sulphuric acid production plant. The off-gas exiting from the second stage gas cooler is now SO_2 rich and is sent downstream for sulphuric acid production.

Importance of upstream dust control

Dry ESPs are an important first step in reducing the dust concentrations entering the sulphuric acid plant, typically to levels below 200 mg/Nm³. However, several factors come into play to assure proper operation of these dry ESPs.

For proper corona charging of particles through controlled gas breakdown by high electric fields, gas temperatures entering dry ESPs must be kept below 400°C. While waste heat boilers can be used to cool the smelter gases before entering the dry ESPs, it is often not the best solution. Varying gas flows from the smelter can result in overcooling of the gas laden with sulphur trioxide. This results in acid condensation, excessive stickiness of particulates, and accelerated corrosion issues. These conditions are hostile to a dry ESP. As a result, corona power in the dry ESP suffers and dust emissions to the downstream gas cleaning system and the sulphuric acid plant may be elevated. Therefore, a poorly performing dry ESP puts additional burdens on the downstream gas cleaning system of quencher-scrubbers and wet ESPs.

To avoid these situations, evaporative coolers (ECs) are a proven way to reduce the process gas temperature before the dry ESP. Dual fluid nozzles that create fine droplets are commonly used. These EC designs control injection rates to accommodate variations in the process flow. As a result, the fine droplets produced by dual-fluid nozzles assure complete evaporation of water before the gases enter the dry ESP.

PHOTO: B&W MEGTEC

Fig. 2 (above) shows the Turbotak atomising nozzle design offered by Babcock & Wilcox MEGTEC (B&W MEGTEC), a proven performer in evaporative cooling applications worldwide.

The role of wet ESPs in maintaining the required reliability of downstream equipment cannot be overstated. Wet ESP performance failures can have serious operating consequences on equipment such as the gas blowers and heat exchangers. A poorly operating wet ESP will also affect the concentrations of contaminants in the sulphuric acid being produced.

Maintaining low levels of sulphuric acid mist (typically below 20 mg/Nm³) and dust (typically below 5 mg/Nm³) is important because such levels reduce dust accumulation in catalyst beds, which leads to increased pressure drop across the bed. The accumulation of dust on booster fan blades is also avoided by the high capture rate of fume and dust in the wet ESP.

CONTENTS
What's in issue 372
COVER FEATURE 1
Sulphur 2017 Conference, Atlanta
COVER FEATURE 2
North America refining
COVER FEATURE 3
Wet ESP designs
COVER FEATURE 4
Sulphur recovery trends

SULPHUR
ISSUE 372
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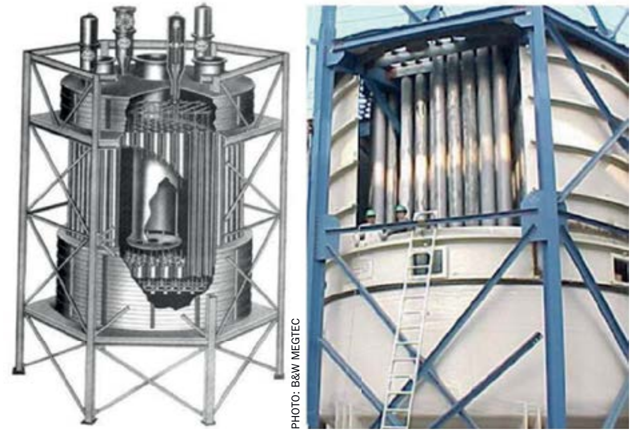

Fig. 3: Up-flow wet ESPs

Fig. 4: Old wet ESP design using lead internals (left) versus new wet ESP design using hex tubes and rigid discharge electrodes (right).

Acid mist removal

Acid mist is highly corrosive in nature and sub-micron in size. Wet technology is an excellent choice for its removal, as a wet ESP uses liquid to remove the collected acid mist and particulate from its collection surfaces. This makes any re-entrainment problem virtually non-existent due to adhesion between the liquid and the collected material. The predominant charging mechanism for sub-micron acid mist particles is diffusion charging. Therefore, the wet ESP is usually designed to produce higher secondary current by using a "narrow" gas passage opening. The higher secondary current is necessary to overcome the current suppression caused by the sub-micron sulphuric acid mist particles. These features greatly enhance the collection of submicron particles. Also, the gas stream temperature is lowered to saturation before entering the wet ESP, promoting condensation and enhancing the collection of soluble acid mist.

Materials of construction

Lead used to be the traditional material of construction for wet ESPs. These wet ESPs normally required extensive maintenance causing concern for the maintenance workers who often had to be moved to other positions because of the elevated levels of lead detected in their blood. Over time, due to increasing health and environmental concerns with lead, and with the development of a variety of new materials, modern wet ESPs have moved away from lead to alternative materials such as plastics, high grade stainless steels and alloy designs.

Wet ESP designs

Wet ESPs can vary greatly in design, materials, gas flow rates and durability, as well as collection efficiency. It is thus important for engineers to recognise the key differences among these various systems.

Wet ESPs of lead design

Fig. 3 shows two different wet ESP models with an up-flow design utilising lead internals. Saturated gas laden with aerosols consisting of dust, fumes, and sulphuric acid mist enters the bottom of the primary stage wet ESP and flows up through round collection electrodes, exiting at the top. Aerosols are charged by corona current and a high-strength electric field created by the localised gaseous breakdown through the application of high voltage on discharge wire electrodes located within each of the collector tubes. The upper and lower casing domes are fabricated of fibreglass reinforced plastic (FRP) using a resin that withstands specified service conditions.

There are variations of up-flow design depending upon site-specific conditions. For the designs shown in Fig. 3, the wet ESP internals are washed periodically from the top and bottom of the collector tubes using a weak acid wash. Since the internals are made of lead, and these are electrical conductors, there is no need for continuous injection of weak acid onto collector tubes to provide grounding through the ESP structure by external means. High-voltage discharge wires are kept taught by bottled weights encased by lead. A four-point suspension is utilised on the discharge electrode carbon steel support frames, which are also covered by lead. A heated purge air system is designed to energise and inform the operator automatically upon failure of the operating purge air fan unit. Purge air is necessary to keep the insulators warm, dry, and free of dust.

B&W MEGTEC wet ESPs

Wet ESP internals of alloy design

Fig. 4 shows the internals of the old lead design compared to the new all-alloy design. In the all-alloy design, the high-voltage rigid discharge electrodes are of a "pipe and spike" design.

The pipe and spike design typically demonstrates a much lower corona starting voltage compared to the "star" shaped discharge electrode wire used in the older lead wet ESP designs, and exhibits a higher level of corona current density for a given operating voltage.

SULPHUR
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PHOTO: B&W MEGTEC

Fig. 5: Old lead wet ESP (left) to be removed and new alloy set ESP replacement (right) installed into existing structure (compact design provides more wet ESP performance per footprint).

Table 3: **Observations of suitability of all-alloy wet ESP materials in a weak sulphuric acid environment**

Application	pH	Chlorides	Fluorides	Bromides	Alloy
Regen sulphuric Acid	0.5 to 1.5	-	-	-	904L
Regen sulphuric Acid	0.5 to 1.5	-	-	X	6 Mo
Cu smelter – silicate	0.5 to 1.5	X	X	-	6 Mo
Cu smelter – no silicate	0.5 to 1.5	X	X	-	C-22
Zn smelter – silicate	0.5 to 1.5	X	X	-	C-276

Source: B&W MEGTEC

For the smelter sulphuric acid plant application, compared to older lead designs, using the high current-emitting pipe and spike discharge electrode design produces a considerable increase in total corona power in each of the primary and secondary wet ESP stages. Maximising corona power has been shown to be essential for maintaining wet ESPs at maximum collection efficiency for a given process load.

Compactness of an all-alloy solution

As seen in Fig. 4, an all-alloy solution using the hex-shaped collector tube bundle design is inherently more space efficient compared to the round-tube design. Consequently, it is possible to offer wet ESPs with increased capacity when replacing an old lead design with an all-alloy solution. Fig. 5 shows the installation of a new wet ESP replacing round tubes with hex-shaped collector tubes resulting in a considerable increase in collection area.

This increased collector tube capacity, coupled with higher corona producing discharge electrode geometry, is conducive to higher collection performance on submicron aerosols of sulphuric acid mist and fine metallic fumes, even when the flow capacity through the wet ESP is increased.

Material selection criteria of alloy materials

In making decisions about the suitability of alloys for wet ESPs, four key factors are important to note:

- operating temperature of the wet ESP;
- pH of the weak sulphuric acid being collected;
- chlorides present in the liquor;
- fluorides present in the liquor.

In sulphuric acid plants, the weak acid is maintained within a temperature range of 16°C to 32°C. Table 3 shows different alloys of considerable promise based on materials coupon testing (material selection should include site-specific corrosion coupon testing to ensure suitability) and actual experience in sulphuric acid plant applications. In the presence of chloride levels below 200 ppm, the weak sulphuric acid liquor has been suitably handled with 904-L in a wet ESP.

Smelter applications experience wide ranges of fluorides in weak sulphuric acid, ranging up to 200 ppm. Metallurgists have allocated corrosion equivalencies between chlorides and fluorides. Equivalent ratios are estimated to be from as low as 10:1, to as high as 100:1. That is, 1 ppm of fluoride could have as much impact as 10 to 100 ppm of chloride in weak acid liquor. Also, there is discussion among metallurgists that the presence of metals in weak hydrofluoric acids could transform the fluoride into a much less corrosive form. Therefore, some amount of total suspended solids containing metals may turn out to be beneficial in resisting corrosion from fluorides for a given alloy.

Depending on the actual severity of corrosion due to the presence of fluorides, the primary choice of materials for this smelter sulphuric acid plant service are 6% Mo alloys and C-276, with C-276 considerably more expensive than the 6% Mo alloys.

A solution for managing the corrosive effects of fluorides in the gas cleaning sulphuric acid plant system is the addition of sodium silicate to the weak sulphuric acid wash loop. Sodium silicate has been shown to reduce the fluoride attack on brick linings, FRP material and catalytic converter supports. Referring to Table 3, the all-alloy wet ESP utilising 6% Mo alloy has been operating successfully for at least four years, where the gas cleaning system utilises a sodium injection system.

Conductive composite material development

A separate initiative by B&W MEGTEC is underway to determine the most robust low-cost materials for acid corrosion duty in the presence of chlorides and fluorides.

These efforts have led to the development of a conductive composite material (CCM) that has superior corrosion-resistance, is resistant to spark erosion, and can withstand most flue gas operating temperatures with short duration excursions in the range of 175°C to 200°C. This CCM is a mix of woven carbon fibres coated with a layer of thermosetting resin and assembled with a proprietary conductive adhesive also developed by B&W MEGTEC.

The CCM performs like stainless steel, with corrosion resistance properties superior to FRP. In addition, it offers power arc resistance, corrosion resistance, temperature resistance, good surface and volume conductivity, good heat dissipation characteristics (no spark erosion or effects from "spit-arcing"), reduced cost of production compared to FRP, resistance to crack propagation due to the carbon fibre cross-linked arrangement, resistance to pitting and crevice corrosion experienced with stainless steel and alloy materials, resistance to wicking (does not absorb moisture that can deteriorate the structural integrity of the material), a high strength to weight ratio providing excellent fracture resistance, and high conductivity that eliminates grounding issues prevalent in carbon impregnated polypropylene or FRP fabrications.

B&W MEGTEC has several patents and patents pending related to this new material (material use, construction, and adhesives innovations). A full-scale CCM-based wet ESP has been operating successfully on HCl service since 2012, and a pilot wet ESP with a CCM tube bundle is available for demonstration and field testing.

Southern Environmental's maintenance friendly wet ESP design

One of the major issues with the maintenance of any wet ESP design is to overcome performance degradation due to material build-up on the discharge electrodes and collecting electrodes, resulting in close clearances and decreased operating voltage and operating current. The closer clearances can also result from the age of the wet ESP. It is typically time consuming and expensive to remove these build-ups and/or clear out close clearances, and it often must be done during a very short turnaround. When it becomes necessary to replace the entire set of collecting electrodes, it typically involves removing the roof of the wet ESP and specialised skilled labour is required to perform the work. Both of these mean longer turnarounds and higher operations and maintenance costs.

In order to address these problems and to make the wet ESP design more maintenance friendly, Southern Environmental has developed an innovative design in which fabric membranes replace lead, exotic metal or plastic collecting electrodes. These membranes are hung in a similar manner as any other collecting electrode but are continuously irrigated with liquid to keep them clean and conductive. The membrane material is typically polypropylene which is readily available and has excellent chemical resistance properties in this low pH environment.

The membrane material typically comes in rolls and allows for easy slide in/out through wet ESP access doors. Once these membranes are in place and the wet ESP is put in operation, any close clearance problems that develop between the membranes and discharge electrodes can be easily resolved by replacing individual membrane pieces. If replacement is not feasible, the affected membrane section can be easily cut-out using scissors or a knife. When the time comes to replace the entire set of collecting electrodes, all work can be performed without removing the roof of the wet ESP.

In 2009, this membrane wet ESP design was selected to replace an aging lead type wet ESP installed as part of a gas cleaning system at a molybdenum roasting facility. Here, ore consisting of MoS_2 is roasted to remove sulphur. This process oxidises moly to MoO_3 and drives off sulphur in the form of SO_2 and SO_3 in the roaster off-gases. The SO_2 and SO_3 rich flue gas from the roasters then passes through a gas cleaning system consisting of cyclones, spray coolers, dry ESP, gas saturator, gas cooler, and wet ESP. The gas cleaning system removes fine particulate, moisture and SO_3 from the flue gas, leaving SO_2. This SO_2 rich gas is then used to make sulphuric acid in a downstream acid plant.

The membrane wet ESP is a tubular, up-flow type design consisting of two modules in series as shown in the picture on page 40. Most components are fibreglass reinforced plastic (FRP), with the collecting surfaces being felted polypropylene membranes. The membranes are continuously cleaned using "weak acid" that has pH of approximately 0.5. As a precaution, the membrane material was replaced after approximately seven years of continuous operation. This took about one week working one shift per day to replace all membranes in both units. The replacement task took place without removing the wet ESP's top roof. Visual inspection of the membrane material showed no noticeable degradation and as such at least ten years life for membrane material in this environment can be guaranteed.

Overall, this innovative wet ESP design solves historical operating and maintenance problems associated with "old-design" wet ESP technologies and is ideally suited to replace aging lead type wet ESPs in non-ferrous metals plants.

Beltran advanced wet ESPs

For engineers and plant designers in the field of gas cleaning, several operational goals stand out:

- achieving the highest level of particle collection efficiency;
- cleaning greater volumes of source gases, with faster throughput speeds; and,
- achieving the greatest reductions in costs related to capital investment, operating cost, energy consumption, equipment maintenance, and long-term equipment replacement.

To help sulphuric acid plants and other industries achieve these goals, the engineering staff at Beltran Technologies, Inc. in New York have been researching and developing a specific type of advanced, innovative precipitator technology which offers proven superior performance and efficiency.

Primarily targeted at capturing submicron-scale particulate matter, saturated sulphuric or other acid aerosols and condensable organic chemicals, the Beltran wet ESP utilises aqueous flushing nozzles to clean the collection surfaces. The captured particles are cleansed from the collection surfaces by recirculating water sprays; residues, including aqueous sulphuric acid, are extracted for further use or disposal. The cleaned gas is ducted to downstream equipment or to the stack, depending on the application. A well-designed and correctly operated wet ESP can clean complex gaseous emissions of particulates and acid mists down to submicron scale (PM 2.5) with up to 99.9% efficiency, and very low energy drain - far superior to other equipment.

The simple elegance of this basic wet ESP concept makes them uniquely versatile over a broad range of industries, applications, operating conditions and gas chemistries. This adaptability is critical to metallurgical and petroleum refining operations, where source gases can be highly variable.

Taking advantage of the inherently low pressure drop of ESPs, Beltran's staff devised a multistage system of ionising rods bristling with star-shaped discharge points. These are encased within square or hexagonal tubes to maximise collection surface area and minimise overall space requirements. The unique electrode geometry generates a corona field 4 to 5 times more intense than that of conventional wet or dry ESPs, resulting in greater particle

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PHOTO: BELTRAN

Fig. 6: Hindustan Zinc Ltd installed wet ESPs engineered by Beltran Technologies Inc. to control smelter emissions and effectively capture and remove fine sub-micron size particulate matter.

migration velocity and adhesivity. The multi-stage charging configuration also avoids corona quenching due to high particle densities, and assures maximum corona field strength with a minimum of energy load.

A persistent challenge for traditional dry-operating precipitators is the re-entrainment of particles from the collection surfaces back into the gas stream due to the use of mechanical or acoustical rapping units. Beltran's design uses a vertical flow and continuous aqueous flushing of wet ESPs to greatly minimise this problem. By eliminating the need for rappers, wet ESPs also reduce the higher cost and energy drain imposed by that equipment. For industries that generate oily or sticky residues, the aqueous flushing also prevents particle build-up, and overcomes electrostatic resistivity and back-sparking on the wet ESP collection surfaces.

Other critical features to look for in advanced wet ESP equipment are sophisticated electronic controls linked to a close-coupled gas flow management system; these can optimise operating parameters such as gas velocity, saturation, temperature, corona intensity, etc., to achieve maximum efficiency.

A major threat to the cost-effectiveness of a wet ESP is corrosion of equipment caused by the harsh chemical components of treated gases. To prevent premature deterioration, Beltran wet ESP systems are constructed of advanced protective materials such as fibre reinforced plastics (FRP) or high nickel-chromium alloys. The high-voltage insulators are continuously cleaned with purge air to further reduce maintenance costs.

Fig. 6 shows the Beltran wet ESP installation at Hindustan Zinc Ltd.

Outotec Editube® wet ESPs

Outotec's Editube wet ESP is the result of many years of product development and customer satisfaction. Around 1980, the Swedish mining and metallurgical company Boliden set out to find a solution to the problems associated with the traditional wet ESPs constructed of lead. Around the same time, new cost effective stainless steel materials specially developed for environments with acids and halides, had been developed by major stainless steel mills in Sweden, materials such as 254 SMO and 2205. After testing different materials in existing wet ESPs at Boliden's copper smelter, 254 SMO was found to be suitable and a wet ESP using this material was developed

In 1984 two such units were installed at the Boliden smelter. Further evaluation using 2205 showed that this lower-cost material would also be suitable and, during 1986-2000, seven units made of 2205 were installed. Collectively, all nine units have been in continuous operation since their installation, without any noticeable corrosion. At this time, Outotec Swe-den was a part of Boliden, and this wet ESP technology was marketed to others through Boliden Contech. Today the wet ESPs are known as Outotec Editube®.

Although there was good experience from the Boliden smelter with the high-grade stainless steel Outotec Editube®, there was some anxiety among other potential users. Some had, for example, tested the new stainless steels in the scrubber sections with less than desirable results. However, the gas at the wet ESP stage is normally substantially less corrosive than at the scrubber stage. First, the temperature is lower, about 35-40°C, compared to around 65°C in the scrubber stage. Second, most of the halides have been removed in the upstream cooling stage, before the wet ESPs. For cases where new wet ESPs should replace old ones it was found practical to take out samples of condensate from the operating wet ESPs to study the corrosiveness. These samples were analysed for free sulphuric acid and halides. Even when the gas contained a considerable amount of acid mist, the condensate from the wet ESPs normally held less than 10-15 % (w/w) free sulphuric acid and in occasional cases up to around 20%, when there was very high acid mist content in the gas. Halides are normally well below 1 g/l in the wet ESP condensates. When comparing these values with isocorrosion diagrams from the suppliers of high-grade stainless steels, one will find that they are normally well below the 0.1 mm/year isocorrosion curves. This explains, why the new Outotec Editube® wet ESPs show extremely high corrosion resistance in practice. To date, Outotec has sold around 50 units made of high-grade stainless.

Practically all users of the Outotec high-grade stainless steel Outotec Editube® have been very pleased with the robustness and reliable operation of these units, especially as they can also handle upset conditions without special precautions. Nevertheless, there are clients who may prefer a reinforced plastic design, mainly due to cost. Higher grade stainless steels are usually more expensive than plastics and in some cases clients may have very unique corrosion concerns. Therefore, Outotec has also designed a plastic Outotec Editube®. These units have round tube collection electrodes made of polypropylene and casings of FRP, materials which are virtually nonflammable. The tubes are spaced closely together in a bundle. The emission system for the plastic Outotec Editube® is designed in the same way as the all-high-grade stainless steel units. In

SULPHUR
ISSUE 372
SEPTEMBER-OCTOBER 2017

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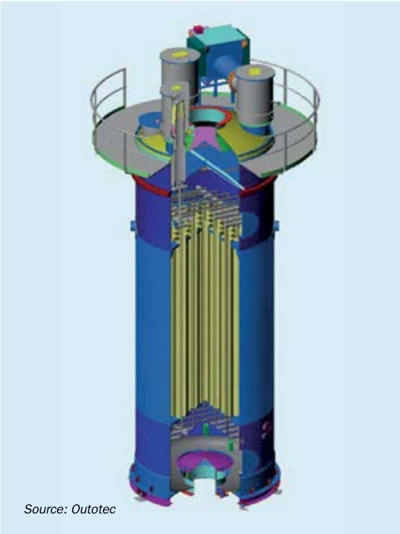
Source: Outotec

Fig. 7: Cut-away view of Outotec Editubes®


Source: Outotec

Fig. 8: Two stage system of self-supported Outotec Editubes®

some cases, emission systems made of nickel-based alloys have been used due to corrosion concerns. Thus, the use of lead is eliminated. Outotec has presently sold around 35 units made of plastic.

In addition to the developments with materials of construction, Outotec has carried out a number of projects to improve the function of various components, such as insulators, emission system, general high voltage design, self-supporting design of the units, gas distribution and a "plug and play solution" (see schematics in Figs 7 and 8).

High voltage design insulator hoods

As there are high voltage electrodes inside the tubes there must also be an electrical insulating system between the high voltage electrodes and the grounded casing. This is the work of the insulator hoods.

Although high voltage systems are commonly used in electric power distribution systems there are factors that make the function of the insulator much more difficult in a wet ESP. The largest challenge is preventing process gas from entering the insulator hood, the acid mist in the process gas will immediately condense on a cold insulator surface. Acid is quite conductive and a flashover (a spark over a surface) will immediately follow over the insulator, possibly cracking the insulator. A cracked insulator would require an unplanned shutdown, thus upsetting production.

A common method of keeping the process gas away from the insulator is to flush the insulator compartment (hood) with ambient air using a fan or blower. The principle is simple: ambient air "flushes" over the insulator and into the process gas. Although proven, it requires maintenance of the air intake filter and moderate checking of the fan/blowers for proper operation. An intake filter can let dust through, this then travels with the air and settles on an insulator, this result is cleaning every 6-12 months (depending on the dust levels on site).

Another more refined principle, used by Outotec, is the heated insulator hood. Here, the process gas is prevented from entering the insulator hood compartment by a "hot air cushion", as the process gas is much colder than the insulator compartment. In addition, another safety factor is that if there is some process gas near the insulator, the high temperature does not allow any acid to condense on the insulator (above dew point). This stops any potential for flashovers.

The only equipment needed for a heated system is a heater and a temperature transmitter, which are both very low maintenance items of equipment. In order to make the heated compartment work well, the design must be done in a consistent way, from the top where the high voltage feed enters the insulator, to the lowest point of the protective tube protruding into the wet ESP. Outotec has been doing extensive test work with the insulator hood design in a special insulator test hood facility to find the proper design.

The advantage of the heated insulator is that when everything is properly designed it just "works"; there is no equipment to service and there is no dust being deposited on the insulator surfaces. Even during short, upset process conditions, the temperature prevents condensation and flashovers. Insulator damage is rare, as the temperature conditions are very stable and there are no flashovers. As an example, one client normally only services his insulators during a planned plant shutdown every 3-4 years, and insulator damage is very rare.

Emission system

The emission system of the Outotec Editube® wet ESP consists of an upper and lower electrode frame and a number of Outotec Edirod® electrodes (Fig. 9), depending on the gas cleaning duty to be performed. The entire emission system is free-hanging. The upper frame is connected through a suspension rod to the insulators located on the top of the unit. In addition to ensuring the corona

SULPHUR
ISSUE 372
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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37


PHOTO: OUTOTEC

Fig. 9: Rigid mast Outotec Edirod® discharge electrode.


PHOTO: OUTOTEC

Fig. 10: Top of wet ESP with platform.

discharge and maintaining the electric field inside the tubes, a few of the Edirod® electrodes also serve to carry the lower electrode frame. These electrodes are referred to as support electrodes. In the end, the free-hanging design of the Edirod® electrode system effectively reduces the inherent forces that the electrodes are exposed to, and their life time is thereby greatly increased.

High voltage system design

As there is high voltage equipment (insulators, hangers, framework supporting the electrodes, and the electrodes themselves) there is also a need to consider a high voltage design for these parts. The two main things to avoid are:

- flashovers – an electric discharge over a surface;
- sparkovers – an electric discharge through the air.

Both of these must be avoided in a wet ESP. A premature sparkover/flashover will limit the possible voltage in the wet ESP and reduce the efficiency of the cleaning. The limiting voltage must always be set by a sparkover between an electrode and the tube wall.

According to the literature, sparkovers and flashovers always start at an initiation point, typically at a sharp point close to the high voltage equipment. From that point there is a propagation phase where an electric leading "channel" is formed in the air or gas. The next stage is a sparkover through the channel.

Besides avoiding sparkovers and flashovers, care should also be taken to avoid unwanted corona effects. A corona is a point emitting electrons. It is seen at the sharp point of the electrodes. This is also the only place where they should occur. A corona effect can be seen as a glowing dim light, at sharper points. The reasons for avoiding coronas are:

- it is a strong initiation point for a sparkover or flashover;
- it emits electrical energy that is better used for particle separation;
- it can age and destroy materials (typically softer materials such as gaskets and seals).

With advances in computational capabilities, it is possible to make electric potential simulations. Nowadays, basing the design of the high voltage equipment on an electric potential calculation is good practice. This gives a good base to avoid sparkovers and flashovers and it is also possible to remove any points with unwanted corona effects.

Self-supporting design

The Outotec Editube® is self supported, with a transformer rectifier (T/R) unit and insulator hoods located on the top. Platforms can also be attached directly to the unit (Fig. 10). Additionally, with the correct design considerations, it could even carry the gas duct inlet and outlets. Thus, with ladders attached for access to platforms and upper parts of the unit, the Outotec Editube® requires no surrounding steel structure.

In its entirety, the Outotec Editube® is designed for a long lifetime with minimum maintenance requirements. In a one or two-stage system, it provides a space-efficient way to reduce the concentration of dust and aerosols from process gas.

Plug and play solution with associated PLC

The Outotec Editubes®, together with necessary auxiliary equipment for flushing, fogging, and instrumentation, constitute the wet ESP plant within the gas cleaning train. Outotec is able to offer a plug and play solution for the wet ESP plant, providing numerous benefits.

The delivery consists of all equipment within the wet ESP plant, including pumps, valves and tanks, all instrumentation, cabling, and a programmed PLC for the control of all necessary systems surrounding the Outotec Editube®.

The main benefits of the plug and play solution are:

- **Interface:** gas duct inlet and outlet, supply of fogging and flushing water to Outotec provided tanks, one Profibus connection to the client DCS:
- **Reliable and stable system and operation:** tested and proven instrumentation and programming for optimised performance.
- **Fast installation:** the entire design under Outotec control allows for more prefabrication, such as brackets for cable trays and pipes, already in the workshop, saving valuable installation time on site.
- **No need for client programming:** the wet ESP plant can act as a standalone island, while a large signal interface still allows for the client to have the desired control of the plant.
- **Complete CE-marking** (or other applicable standard) of the entire wet ESP plant.

Combined with the self-supporting properties of the Outotec Editube®, Outotec can therefore provide a true plug and play solution – a wet ESP plant in its entirety, pre-programmed for stable and reliable operation, without the need for any supporting steel structure.

CONTENTS
What's in issue 372
COVER FEATURE 1
Sulphur 2017 Conference, Atlanta
COVER FEATURE 2
North America refining
COVER FEATURE 3
Wet ESP designs
COVER FEATURE 4
Sulphur recovery trends

SULPHUR
ISSUE 372
SEPTEMBER-OCTOBER 2017

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PHOTO: OUTOTEC

Fig. 11: Compact tube bundle

Circular tube design

The traditional lead wet ESPs usually had square-shaped collection electrodes. With high-grade stainless or PP plastic it was natural to make a circular tube design. The advantage with the round tube is that the distance from the wall to the centrally located emission electrode is the same in all directions perpendicular to the axis. The design of the emission electrodes is also very important for the efficiency of wet ESPs. The Outotec Edirod® electrodes are designed as rigid masts with sharp needle points for enhanced current density. In combination with the round tubular collecting electrodes, an optimum electrical field is achieved, which results in superior removal efficiency. At the same time it was possible to make a tube bundle arrangement where the tubes were spaced very closely together to create a large collection area within a small vessel (Fig. 11).

Gas flow/gas distribution

Another important factor is the process gas distribution over the tube bundle. The pressure drop over the tube bundle is low so the tube bundle will not correct any maldistribution.

Gas distribution is important, but there are actually two different cases of "poor gas distribution". Having too low a velocity in a number of tubes is not an issue, one is merely using the tubes at a lower gas capacity, but having too high a process gas velocity in a number of tubes can be devastating since the tubes can more or less be regarded as a "by-pass" of uncleaned gas, as the gas cleaning efficiency in the highly loaded tubes is poor and the total gas flow in these tubes is relatively high. Therefore, good gas distribution must be maintained for a well-functioning wet ESP.

The Outotec Editube® has a two-stage gas distribution system with hole plates that have proven to work very well. The design has been verified by numerous units in operation with very good removal efficiency values, something that cannot be achieved with poor gas distribution. The gas distribution has also been verified by actual measurements on fabricated units at the workshop. Recent gas distribution work uses CFD (computational fluid dynamics). Work has been ongoing to start a CFD check for every new unit, also including bends in the upstream gas ducting. This allows fine tuning by changing the cut pattern in the gas distribution plates.

One example of the efficiency of high-grade stainless steel wet ESPs is the installation of four 254 SMO Outotec Editube® units at the Norzink smelter in Norway in 1995[3]. In this smelter a special mercury removal system had been in operation since 1976. Together with the other parts of the wet gas cleaning system, this permitted the production of sulphuric acid containing less than 1 ppm Hg. Market demand for even lower mercury levels in sulphuric acid led to subsequent changes to the gas cooling and wet ESP stages. The wet ESPs are very important for the mercury removal efficiency, as mercury is present in the gas in both particulate and vapour forms. Therefore, the dust removal efficiency of the wet ESPs is critical. After installation of the new equipment, the mercury levels in the output acid was reduced from 0.4 - 0.8 ppm, down to 0.1 - 0.2 ppm. A large contribution to this reduction was attributed to the new Outotec Editubes®.

Wet ESP upgrade at Nyrstar

Recently, one of Outotec's clients, Nyrstar, contacted Outotec's technology teams in Australia and Sweden to discuss replacing their older, lead-lined wet ESPs at their Hobart Zinc Refinery in Tasmania, Australia.

The Outotec Editube® product is perfectly suited to this process duty. So, after an assessment of the gas to be cleaned, both the high grade stainless steel and plastic version of the Editube® were submitted for discussion. In this instance the plastic Editube® was selected and contracts awarded.

Whilst the technology teams were busy designing and building this customised solution, Outotec was also asked to be involved with the planning of the installation. While this is fairly routine, with Outotec always heavily involved with installation and commissioning activities to ensure the best possible "start of life" for the wet ESP and the teams that will operate them, this time the client wanted to execute the complete swap out in only 14 days – the challenge was accepted.

Working tirelessly throughout the project delivery stages to streamline the installation process Outotec also mobilised resources from the Swedish based site installation/commissioning team. As a result of this and the close working relationship with Nyrstar the installation took only 12 days. Both Outotec and Nyrstar are proud of this result and continue to have a great working relationship.

This a great example of Outotec's "complete solution" delivery, where Outotec is present from the project inception through to site pack up.

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SULPHUR
ISSUE 372
SEPTEMBER-OCTOBER 2017

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From low cost by-product to premium AS granules

PHOTO: tkIS

thyssenkrupp Industrial Solutions (tkIS) has developed a new fluidised bed granulation process to convert low cost by-product ammonium sulphate solutions into premium grade granules. **Jens Mathiak** of tkIS, describes the process and reports on the current status of the technology.

High-quality fertilizer for optimum plant growth

Plant growth depends on the nutrient content of the soil. A balanced distribution of primary and secondary nutrients as well as microorganisms ensures an optimum crop yield. Nitrogen is an essential nutrient, and so is sulphur.

In today's world a cleaner environment, tail gas desulphurisation and less acid rain now mean that soils especially those that are neutral or alkaline require the controlled addition of a fertilizer additive which contains sulphur: ammonium sulphate.

Ammonium sulphate feeds sulphur and nitrogen to the soil. With its colloidal components, the fertilizer binds to clay particles in the soil, ensuring a long-term supply of nutrients. Ammonium sulphate is thus perfect for plants with a long growth period and in areas with high rainfall. In addition to acting as a long-term plant nutrient, the sulphur also promotes the transfer of micronutrients, such as manganese, iron and boron, from the soil to the plants.

Ammonium sulphate solutions are a pertinent industrial by-product. In addition to sulphate, nitrogen and sulphur are key components of this fertilizer, which is mostly marketed in the form of crystals. In its state-of-the-art plants, thyssenkrupp has developed a process to convert ammonium sulphate solution to granules. The key advantages compared with liquid and crystalline solutions are improved storage as well as spreading and mixing properties.

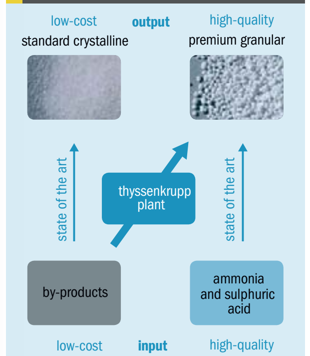
Alternative granulation plants are not able to process ammonium sulphate solutions. These plants require expensive ammonia and sulphuric acid to achieve higher-priced premium product characteristics (see Fig. 1).

Low-cost granulation – premium prices

The granular form as a unique selling point and the high profit margin are two very good reasons to choose the thyssenkrupp ammonium sulphate process. In addition, due to the large quantities produced, crystalline ammonium sulphate is a mass-market product while granulated ammonium sulphate is produced by only a few suppliers in relatively small quantities. Demand is accordingly high and there are also sales opportunities in niche markets.

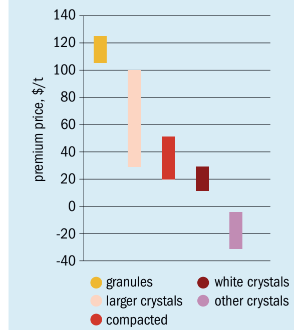
The new process developed by thyssenkrupp offers the opportunity to convert low-cost by-product into valuable premium granules. The price for premium granules is significantly above the prices of standard products at around $100 per tonne (see Fig. 2).

Fig. 1: **Ammonium sulphate production processes**



Source: tkIS

Fig. 2: **Ammonium sulphate product prices**



Source: Integer Research

Table 1: **Product specifications**

Nitrogen content	~ 21 wt-%
Sulphur content	~ 24 wt-%
Moisture	< 0,5 wt-%
Hardness	~ 3.000 g
Bulk density	750-850 kg/m³
Diameter 2-4 mm	~ 90%

Source: tkIS

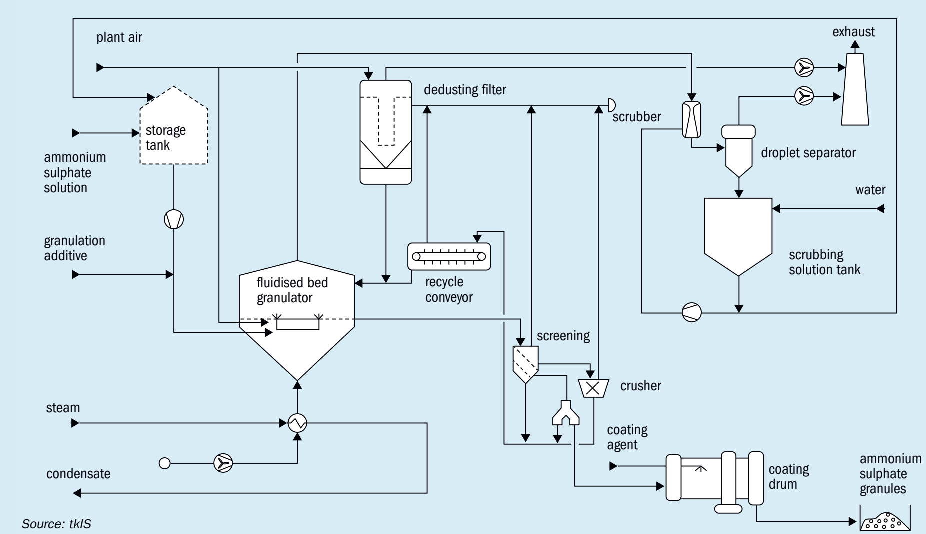
Conversion of liquid ammonium sulphate into granules

The fluidised bed granulation process can produce ammonium sulphate with a low moisture content to reduce caking tendency during storage. Long term storage tests are ongoing and results will determine the transportation, storage and coating requirements. The size of the granules is adjusted by screens in the process to be compatible with other fertilizers. This offers the opportunity for farmers to distribute the granules homogeneously and is also useful if bulk blending with other fertilizers is considered.

The chemical composition is 21 wt-% nitrogen and 24 wt-% sulphur (see Table 1). Classification as fertilizer is defined by the quality of the ammonium sulphate solution used as feedstock. The process itself (Fig. 3) does not jeopardise the classification.

The fluidised bed granulator is the centrepiece of the production plant (see Fig. 4). It is where the liquid ammonium

Fig. 3: **Fluidised bed granulation process for the production of ammonium sulphate**



Source: tkIS

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Fig. 4: The fluidised bed granulator is the centrepiece of the production plant.

sulphate is turned into a solid product. The liquid ammonium sulphate solution is sprayed on the seed granules. The droplets stick to the small solid particle and the water phase is removed by applying hot air. Hence, the granules grow bigger in the fluidised bed granulator (see Fig. 5).

Downstream of the fluidised bed granulator the particles are screened in oversize, undersize and product granules. The oversize granules are crushed and returned to the inlet of the fluidised bed granulator together with the undersize particles. To maintain a stable process the particle balance has to be maintained. Therefor a partial stream of product granules can be recycled to the fluidised bed granulator as well.

The particles in the granulator are fluidised by a hot air stream. One option is to apply steam for air heating. If hot off gases are available at the production site from adjacent plants these can be used to reduce operating costs. The air from the granulator is dedusted by scrubbing and sent to the environment as clean air.

Integration of this new process into existing chemical complexes is essential for economic success. Besides the heat integration already mentioned there are also opportunities within the combination of existing crystallisers. If a fluidised bed granulation plant is installed parallel to a crystalliser the load of the crystalliser will be reduced. As a matter of fact this would lead to the production of larger crystals.

Reflecting the premium prices of larger crystals the economic benefit would be double: Higher prices for the granules produced in the new fluidised bed granulation plant and higher refund for larger crystals produced in the existing crystallisation plant.

Development of a new process

Ammonium sulphate tends to produce dust and form granules with low hardness. The toughest challenge during development of the new process was to find a suitable granulation additive. Mixing of the feedstock with the liquid additive is performed before spraying the solution onto the seed granules.

The development started with a small lab scale single nozzles test facility operating in batches. The core process parameters were identified and the granulation additive was selected. In a second phase a technical scale facility was used to demonstrate continuous operation and to identify extended process parameters like the recycle ratio. Finally upscaling was demonstrated in a pilot plant which was built to mitigate the risks and to demonstrate balance of plant. The pilot plant has a capacity of 12 t/d.

Approximately 85% of the global annual ammonium sulphate production uses solutions as by-product from upstream processes. The quality of these solutions can deviate quite significantly. On the other hand granulation can be a sensitive process for some impurities. Hence, the pilot plant was not only used during the development phase, but will also be utilised to test ammonium sulphate solutions in the feasibility phase before deciding on the investment of installing a fluidised bed granulation plant.

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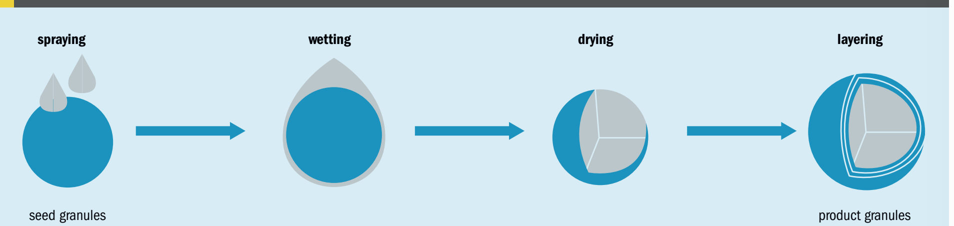
1. Integer Research Limited "The global ammonium sulphate market service", 2013.
2. Uhlemann, Hans: "Wirbelschicht-Sprühgranulation", Berlin, Springer, 2000.

Fig. 5: **Conversion of liquid ammonium sulphate solution into granules**



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Sulphur recovery trends

Sulphur projects around the globe face numerous design challenges to increase sulphur recovery efficiencies, reduce SO_2 stack emissions and deliver fast track schedules. Over the following pages we report on recent projects by Jacobs, Siirtec Nigi and Amec Foster Wheeler.

JACOBS

World class recovery at SAMREF with EUROCLAUS® upgrade

M. van Son and **R. van Grinsven** (Jacobs Comprimo® Sulfur Solutions) and **K.S. Ghazal** (SAMREF)

SAMREF (Saudi Aramco ExxonMobil Refinery) recently completed the design and successful start-up of their newly retrofitted EUROCLAUS® unit. Jacobs provided the required engineering, inspection, pre-commissioning, start-up and performance test support. This article reports on the development of the project and how the project resulted in the highest confirmed overall sulphur recovery efficiency (SRE) from a facility with EUROCLAUS® technology.

SAMREF was running two three-stage 220 t/d sulphur recovery units achieving a sulphur recovery of up to ~97.5%. Both SRU-1 and SRU-2 were designed to process both amine and sour water acid gas (SWAG), but normally only one unit was processing SWAG. A third unit, SRU-3, had recently been taken into operation as part of the clean fuels project, processing amine acid gas (AAG) only and was designed to achieve a guaranteed sulphur recovery efficiency of 97% with a designed capacity of 220 t/d. Based upon SAMREF's agreement with the local environmental regulator, the refinery's sulphur recovery efficiency needed to be increased from 97.5% to 99.2% by the end of 2015. As a result, SAMREF evaluated several technologies and after thorough evaluation it was decided to install a tail gas clean-up (TGCU) EUROCLAUS® retrofit unit. The technology is licensed by Jacobs and the project was executed by its Comprimo® Sulphur Solutions Group. Jacobs guaranteed an SRE of 99.4% at start of run (SOR) and 99.3% at end of run (EOR).

Fig 1: **Typical EUROCLAUS® configuration**

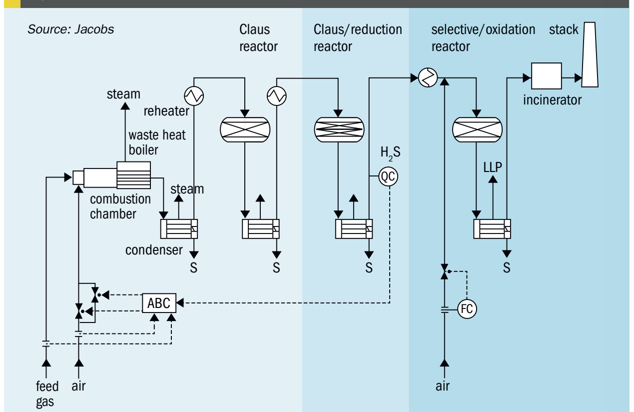



PHOTO: JACOBS

SRU/gas processing industry experts in front of the TGCU unit at SAMREF.

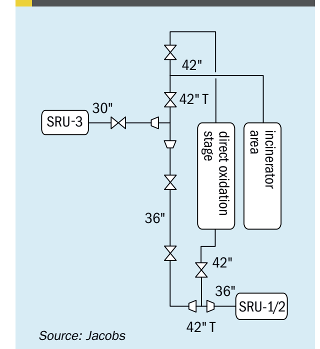
The EUROCLAUS® process is based on the selective reduction of SO_2 present in the Claus process gas to elemental sulphur and H_2S in a selective reduction stage (EUROCLAUS® stage). This stage is operated by H_2S control and is followed by the selective oxidation stage, where H_2S containing gas is oxidised to elemental sulphur by passing it over a special selective oxidation catalyst. The typical configuration of a EUROCLAUS® unit is shown in Fig. 1.

The SAMREF TGCU project consisted of converting SRU-1, SRU-2 and SRU-3 to EUROCLAUS® operation and required the following modifications to meet the overall sulphur recovery requirements:

- Installation of a common 660 t/d selective oxidation stage with bypass line and triple offset butterfly valve.
- Installation of the EUROCLAUS® hydrogenation catalyst in the 3rd Claus catalytic reactors in all SRUs.
- Utilisation of titania catalyst in the upstream SRUs.
- Installation of Jacobs's Advanced Burner Control system (ABC) in all three SRUs.
- Using and upgrading the SRU-3 thermal incinerator during the design phase for the total tail gas flow from the new selective oxidation stage or SRU 1, 2 and 3.
- Resolving the following bad actors essential for the Jacobs ABC control:
  - upgrading the main air control valves for SRUs 1 and 2;
  - resolving the deficiency with the SRU 1 and 2 main air flow element (annubars);
  - restoring the automation of SRU 1 and 2 vent controllers of the combustion air blowers;
  - major improvement in the reliability and performance of all three SRU tail gas analysers by closely working with Ametek/AIMS analyser experts;
  - restoring the functionality of the SWAG (sour gas) flowmeters to SRUs 1 and 2;
  - reduction of the ammonia content in the amine acid gas
- Triple offset butterfly valve in the tail gas lines from SRU-1 and SRU-2 to their dedicated incinerator.
- Addition of rupture pin safety valves to the existing SRU-1, SRU-2, with discharge into the existing incinerator inlet lines, as well as rupture discs on SRU-3 with discharge into the new Incinerator inlet line. These devices protect the upstream equipment on each SRU in the event that the TGCU inlet and bypass valves are both closed

Fig. 2 shows the final configuration.

Fig 2: **Final configuration**



One of the main components in the successful operation of the Jacobs EUROCLAUS® technology is the proper control of the H_2S concentration from the 3rd stages in each SRU. As, in this particular design, there were three SRUs feeding into a common TGCU stage, the control of the H_2S concentration from each SRU was handled independently with the existing tail gas analysers, which were converted to control on H_2S concentration instead of conventional 2:1 ratio control.

The Jacobs Advanced Burner Control (ABC) system was installed in all three SRUs to maintain tight control of the H_2S concentrations in the tail gas from each unit to the TGCU. In addition, a common tail gas analyser was installed at the inlet of the TGCU to be able to properly control the oxidation air required for the selective oxidation reaction with high accuracy as well as verify the operation of the upstream individual analysers. In order to be able to have continuous calculation of the performance of the TGCU, SAMREF elected to install a tail gas analyser at the outlet of the common TGCU stage, which analysed for SO_2, H_2S, COS and CS_2. This analyser, which is not commonly installed due to cost, provides operator insight into the operation and a tool to make adjustments, when needed.

Moreover, it is worth mentioning that SAMREF's project team deployed the following design improvements to the TGCU retrofit EUROCLAUS® unit as result of learnings by Saudi Aramco and Jacobs:

- Design improvements in the TGCU inlet feed and bypass valve to overcome sticking and corrosion issues.
- ControTracing of the coalescer for better heating.
- Complete ControTracing of the coalescer and outlet piping from the new TGCU as the process gas is operated near the freezing point of sulphur.
- Implementation of a revised line up for the 4th reheater and inlet and bypass lines around the selective oxidation stage.
- Automated nitrogen purge upstream of the TGCU reactor, condenser and coalescer.
- Eliminated the requirement of sulphur pit eductors for the TGCU facility as a sulphur collection vessel was incorporated into the design instead of sulphur pit. this increased the reliability of the vent gas system.
- Sulphur trapping devices (SulTraps™) instead of seal legs.
- The expected downtime in SAMREF's TGCU is considerably lower due to:
  - reduced risks of sulphur fires due to the revised line-up;
  - reduced TGCU bypasses, due to a more stable control and therefore, less temperature excursions;
  - reduced risk of catalyst damage/abuse avoiding catalyst sulphidation which will call for repeated rejuvenation, shorter catalyst lifetime and unexpected maintenance shutdowns.

The overall sulphur recovery efficiency is continuously calculated and displayed using the following inputs:

- feed gas flows to each SRU;
- calculated tail gas flows of each SRU (part of the ABC control);
- calculated tail gas flow to the TGCU; oxidation air flow;
- H_2S and SO_2 losses in the TGCU off-gas;
- COS and CS_2 losses in the TGCU off-gas (initially assumed values and updated after the performance test run);
- calculated sulphur losses in the TGCU off-gas, based on the outlet temperature from the final condenser.

The construction of the TGCU ran from May 2014 until mechanical completion in August 2015. The existing SRUs were subsequently shut down to install new catalyst and rectify the bad actors to ensure successful implementation of the EUROCLAUS® technology. These shutdowns were managed with minimum to almost no economic impact on the refinery. In December 2015 the new TGCU was brought on-line thereby complying with the royal commission requirements in time. After the successful start-up, the overall performance of the sulphur recovery units was tested in March 2016 by Sulphur Experts in the presence of Jacobs, Ametek/AIMS analyser experts and SAMREF. During the performance test, the unit was optimised using the available SRU and TGCU tail gas information and the calculated overall sulphur recovery efficiencies were determined to range between 99.61% and 99.76%. These values were confirmed between the TGCU outlet gas analyser and the Sulphur Experts analysis and are the highest recoveries to date for the Jacobs EUROCLAUS® technology. Since the test run the overall sulphur recovery efficiency is consistently above 99.6%

The following parameters are believed to have contributed to the record high recovery with this technology:

- Optimisation of the upstream controls in the AAG and SWS to get a more stable feed to the SRU trains.
- Titania catalyst in the first and second converter resulted in extremely low COS

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and CS_2 concentrations in the tail gas to the TGCU.

- High sulphur recovery in the SRU trains upstream of the TGCU (3+1 arrangement) resulted in the ability to maintain low H_2S concentrations to the selective oxidation reactor.
- Upgrade of the tail gas analysers in the existing units, together with good training and improved maintenance attention, resulting in a much higher availability of the tail gas analysers downstream of the SRUs and at the inlet of the TGCU. This allowed for better control of the SRUs and a better survey of the TGCU operation.
- Proper ammonia destruction in the reaction furnaces of SRU-2 and SRU-3 allowed for minimisation of the temperature from the final condenser.
- Installation of the EUROCLAUS® hydrogenation catalyst in the third reactors of each SRU minimised the SO_2 into the TGCU thereby resulting in a very low SO_2 content from the TGCU.
- Continued development of the selective oxidation catalyst has resulted in higher sulphur yields of the TGCU stage.
- The excellent work relation between Jacobs and SAMREF's project team since the early design phase up to date which resolved various issues and enhanced SAMREF's technical knowledge in the EUROCLAUS® technology.
- Jacobs' direct involvement in the tuning of the SRU and TGCU controllers. Also the upstream controllers have been tuned in close cooperation with the SAMREF process control team.

In order to have consistent high sulphur recovery efficiencies from SRUs, it is essential to have:

- reliable analysers and keep these reliable by spending sufficient time on checking and preventative maintenance by a specialised analyser group within the refinery;
- stable acid gas flow and composition to the SRUs;
- experienced and well trained DCS operators.

Further optimisation may still be possible of the continuous operation by installing acid gas feed analysers and connecting the output from these analysers to the Jacobs ABC+ system to have on-stream correction for compositional changes. In addition, as the excess oxygen levels from the EUROCLAUS® selective oxidation reactor need to be kept to a minimum level to prevent further oxidation of sulphur to SO_2, the installation of an on-stream oxygen analyser may be reconsidered. New technology, proven to be reliable in SRU environments, has become available.

With the installation of a tail gas analyser downstream of the TGCU, it is further possible to actively control the inlet temperature to the selective oxidation reactor, thereby maintaining the highest combination of activity and selectivity of the catalyst during all operating conditions.

In conclusion, the close cooperation between Jacobs and SAMREF on this project has resulted in the highest sulphur recovery for a EUROCLAUS® unit to date with still some potential for further improvement available. Jacobs is continuing the development of the technology to approach the sulphur recovery values typically seen from amine based tail gas clean up units, with much lower capital and operating costs. ■

SIIRTEC NIGI

SRUs for Jurassic production facilities in North Kuwait

C. Scassa

In this article Siirtec Nigi (SN) discusses key aspects faced during the design phase of the sulphur recovery unit (SRU) that forms part of the Jurassic Production Facilities at Sabriya in North Kuwait.

A second SRU, identical to the one to be installed in Sabriya, will be installed in Jurassic Production Facilities at East Raudhatain, North Kuwait.

The SRU consists of two Claus sections in parallel, with a capacity of 100 t/d of sulphur each, two sulphur degassing sections, one common tail gas treatment section (including dedicated amine regeneration) based on SN technology, and common incinerator and utilities (see Fig. 1).

The SRU contract for Sabriya was awarded to SN in February, 2016, from Schlumberger (SLB), which was awarded the complete oil and gas plants contract on a BOO (build, own, operate) scheme by Kuwait Oil Company (KOC). Similarly, the SRU contract for East Raudhatain, was awarded to SN in August, 2016

The entire SRU was intended as a "fast track project", to be designed, fabricated and delivered within 20 months from contract award.

SN is responsible for the engineering activities for the entire SRU and supply of all the above mentioned sections, with the exception of the TGTU amine regeneration, which is supplied by SLB.

During the development of the project SN had to face up to several issues, none of them is actually new or unique, but all of them were contemporary and present in this project, each one affecting the other.

As per the contract, the required sulphur recovery efficiency was 99.4% only, however, the limitations on SO_2 emissions at the stack, as per KEPA standard, are set at 250 ppmv (much more stringent). In order to meet this SO_2 limit, without the need for any dilution at the stack and without any SO_2 scrubbing, SN proposed an amine based tail gas treatment (TGT) based on SN HCR technology and use of catalyst with proven capability to convert COS and CS_2 generated in the unit.

In order to limit H_2S at the top of the TGT absorber as much as possible, formulated solvent TG-10 from INEOS was selected in the HCR. This choice was mainly dictated by the need to allow some COS and CS_2 breakthrough from the Claus and TGT catalyst reactors, which cannot be excluded in end of run (EOR) conditions.

The acid gas feedstock composition is variable depending on the operating scenario, therefore, the SRU is designed to handle acid gas, where the H_2S concentration may change from 50 vol-% up to 75 vol-%. Moreover, the acid gas comes from an upstream acid gas removal unit, which is designed with a hybrid solvent, which suffers hydrocarbon pick-up from the gas, including BTEX.

The final data about the feedstock were only determined in June 2016.

In order to ensure sufficient temperature in the thermal reactor to destroy BTEX, an acid burner specifically designed for co-firing has been selected, supplied by Fives Pillard. Preheating of both acid gas and

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combustion air allows use of co-firing during operation to be reduced to a minimum.

No steam network is available outside of the SRU. Only demineralised water, free of oxygen, is available at battery limits. Therefore in order to allow heating up of the critical services (sulphur lines and sulphur pits) a dedicated steam generation package is included in the system.

Steam production is balanced with internal consumption but, in order to avoid any steam export and to limit demi water consumption, any extra steam generated in the unit is condensed inside of battery limits.

Furthermore, no cooling medium is available from battery limits. SN has therefore compared the provision of a dedicated chiller inside the SRU with the installation of a cooling water system, dedicated to the TGT and ancillary amine regeneration section. SN, together with suppliers of cooling water packages with specific experience in installations in desert environments, investigated the best arrangement with the aim of ensuring operation even in case of sand storms and in order to limit the water make-up as much as possible.

Another issue during the design phase was the preparation of the HCR catalyst.

As per SN practice, use of an inline heater is not recommended, leading to several operational issues, if compared with high pressure indirect steam heaters.

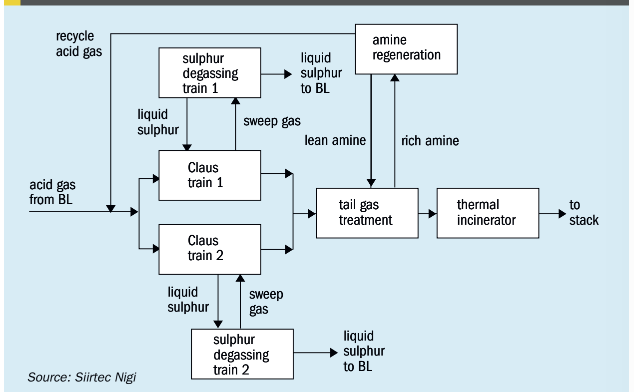
SN HCR tail gas treatment allows operation without any external source of hydrogen and without the extra hydrogen generated by an inline heater.

Nevertheless, for catalyst preparation the presence of hydrogen is required. In the standard catalyst preparation procedure hydrogen and hydrogen sulphide (typically from acid gas) are injected into hot nitrogen and recirculated through the catalyst bed. For this specific project no external source of hydrogen was available and most of the catalyst suppliers did not recommend injection of acid gas, due to the presence of BTEX in the acid gas.

Moreover, the presence of residual oxygen (up to 1 vol-%) in the nitrogen stream form the battery limit could not be excluded. SN developed with each catalyst supplier a specific procedure to presulphide the catalyst, but at the end of the day, for the first start-up, SN has chosen to install a specific Co-Mo catalyst in pre-sulphided form.

The SRU is being supplied in modules, where feasible, in order to minimise erection time at the site. The modules will be delivered to the Sabriya field in September 2017.

Fig 1: Sabriya SRU – block flow diagram



Source: Siirtec Nigi

Sabriya SRU 3D model

AMEC FOSTER WHEELER

State-of-the-art sulphur recovery in Latin America

N. Watts, **S. Kafesjian** and **Q. Kotter**

This case study is a follow-up to the previously published article in *Sulphur* no. 366, page 44 and includes a summary of the start-up, performance testing, and early operational experience.

To meet new SO_2 emission limits, a major refinery in a rapidly developing Latin American nation recently completed installation of a middle distillate hydroprocessing unit. A new amine regeneration unit and sour water stripper separate the H_2S (and ammonia), from which elemental sulphur is recovered in a new modified-Claus sulphur recovery unit (SRU). The design basis of the SRU feed streams is shown in Table 1. The Claus unit is followed by a hydrogenation/amine tail gas treating unit (TGTU).

Atmospheric emissions of SO_2 from the SRU must meet the standards of the International Finance Corporation (World Bank), which specifies that the stack effluent has a maximum SO_2 concentration of 150 mg/Nm³ (at 3% O_2 dry). As a direct result of this project, residents of nearby and regional communities benefit from greatly reduced refinery and mobile source SO_2 emissions. Previously, refinery acid gas containing H_2S was disposed of by combustion in a refinery heater with no emission controls, which released significant SO_2.

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Table 1: Design basis feed compositions to SRU

Component mol-%	AAG 1	AAG 2	SWS gas
H_2S	72.4	90.0	23.6
H_2O	13.3	9.5	42.3
HC	2.1	0.5	0
NH_3	0	0	34.1
CO_2	12.2	0	0
Total	**100**	**100**	**100**

Amec Foster Wheeler's proprietary sulphur recovery technology was selected for the SRU and TGTU. The SRU section consists of two identical parallel trains including common feed stream KO drums, separate thermal and catalytic stages (two in series), heat recovery and multi-pass sulphur condensers. The SRU trains are designed to process the design acid gas feeds in parallel during normal operation with atmospheric air combustion, or individually using low-level oxygen enriched air (up to a maximum of 28 vol-% oxygen). A common TGTU, consisting of a hydrogenation/hydrolysis reactor, followed by direct contact cooling, MDEA treating and regeneration, treats SRU tail gas and enables very high sulphur recovery. TGTU off-gas (or SRU tail gas during TGTU outage) goes to an incinerator with waste heat recovery, then to the atmosphere. Liquid sulphur product is collected in a below grade concrete pit using conventional static head seal legs, and pumped to solidification and bulk storage. Sulphur degassing is not required (Fig. 1).

Post-process design scope

Amec Foster Wheeler's scope of engineering services included preparing the process design package (PDP), and providing home office and on-site engineering support during the detailed engineering, construction, commissioning, and start-up phases. In addition to standard deliverables, the process design package included the detailed design of Amec Foster Wheeler proprietary equipment in the SRU and TGTU. Engineering support activities after PDP completion included frequent correspondence with the client to answer questions, reviewing the specifications and drawings prepared by the detailed engineering contractor and equipment fabricators, inspecting critical equipment installation in the field, assisting with operator training, and assisting with the startup.

Pre-startup inspection of the unit by Amec Foster Wheeler personnel proved highly valuable, as several potentially serious issues resulting from deviation from basic design documents were identified and remedied before start-up, including the following:

- acid gas burner pilot gas and air metering instrumentation omissions;
- critical piping and valve steam jacketing/tracing deficiencies ;
- sulphur rundown piping sight glass installation deficiencies;
- critical SRU acid gas burner tile installation deficiencies;
- SRU waste heat boiler front tube sheet refractory/ferrule damage and incorrect rear tube sheet design;
- defective tail gas incinerator burner tile installation;
- incorrect insulation of refractory lined equipment.

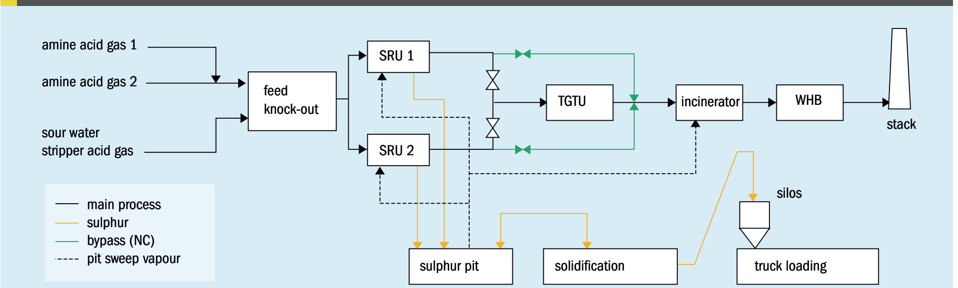
The inspections and subsequent corrective actions successfully minimised start-up problems. Noteworthy problems were limited to acid gas burner pilot flame instability and sulphur rundown piping plugging resulting from steam trap deficiencies. In addition, misunderstanding of recommended acid gas burner control system design and operating procedures by the client and detailed engineering contractor resulted in confusion regarding burner operation, safety system functions and trip points. Consequently, nuisance tripping problems occurred during initial start-up, requiring correction prior to introduction of acid gas.

Amec Foster Wheeler's scope also included supply of its proprietary acid gas burners for the two SRU trains. The acid gas burner is a key feature of the thermal stage of the SRU. The burner design, developed specifically for combusting acid gas, achieves the critical objectives of partial oxidation of H_2S and complete destruction of ammonia and hydrocarbons, and has been proven in a wide range of SRU applications.

Start-up and performance testing

Following the successful start-up of the SRU/TGTU, third-party performance tests of the units were coordinated with the concurrent start-up and testing of the distillate hydrotreater. Test conditions matched the design criteria reasonably well, however the SRU sour water stripper acid gas feed rate was just 80% of the design rate. Furthermore, incinerator stack SOx sampling was not done during the initial tests due to unspecified TGTU absorber operational problems, including contamination that led to amine foaming.

Fig 1: Overall configuration of sulphur plant



Source: Amec Foster Wheeler

Apart from this exception, the operational and performance tests were successfully carried out with consistently superior results, and the unit has operated as designed. Highlights of the performance test results are shown in Table 2. As noted, all process guarantee parameters were met or exceeded.

Because of the positive test results on all aspects of the unit, the client issued the unit acceptance certificate without incinerator stack SOx test results. Recent information received just before publication has confirmed that stack SOx comfortably meets the emission limit. SOx concentration was reported as 65 mg/Nm³ (dry @ 3% O_2). Amec Foster Wheeler continues to provide technical support to ensure optimum operation of the unit.

In conclusion, this case study exemplifies how proven technology applied by experienced engineers, combined with effective management and strong client relations come together to produce an excellent project outcome for all parties, including a positive environmental impact. ■

Table 2: Performance test summary

Test parameter	Test result	Guarantee
SRU hydraulic capacity (% of design)	100	100
SRU once-through sulphur recovery efficiency (%)	98.0	96.05
Residual NH_3 @ thermal reactor outlet (ppmv)	82	n/a (150 normal limit)
Residual hydrocarbons/ BTEX @thermal reactor outlet ppmv)	none detected	n/a
Claus catalyst bed activity	very good/equilibrium Claus conversion achieved	n/a
Waste heat exchanger/ sulphur condenser tube pass outlet temperatures	as expected per design	n/a
Final sulphur condenser tube pass outlet temperature	slightly higher than design, but acceptable	n/a
Tail gas catalyst bed activity	very good/equilibrium conversion of all sulphur species achieved	n/a
Stack - reduced sulphur compounds	none detected	H_2S < = 5 ppmv
Incinerator stack SOx concentration (mg/Nm³ (dry @ 3% O_2))	65 (reported)	150 (maximum)

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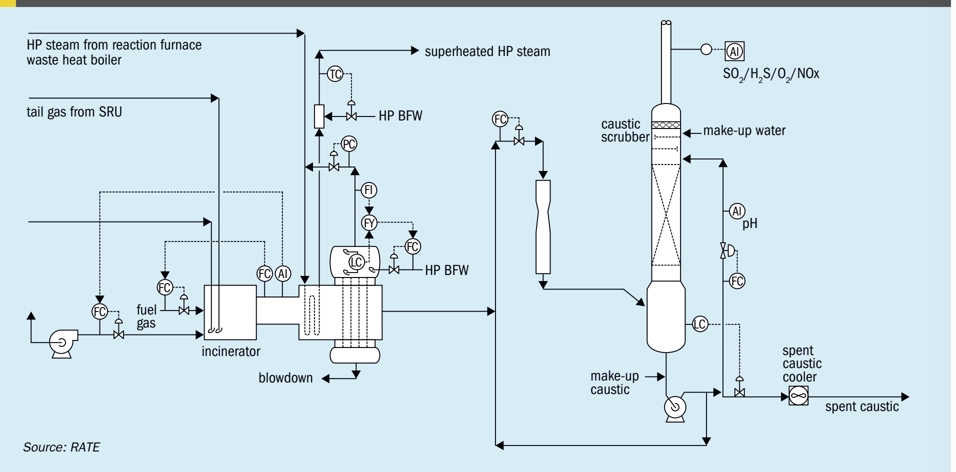
Improving emissions for a cleaner environment

M. Rameshni and **S. Santo** of Rameshni & Associates Technology & Engineering (RATE) report on a new zero emission tail gas process for sulphur recovery facilities. RATE's Super Enhanced Tail Gas Recovery (SETR) process can be added to any Claus process or tail gas treating unit after the incinerator and before the stack. It has lower capital and operating costs than a caustic scrubber, requires no chemicals and produces no waste stream.

Fig 1: **Thermal incineration with RATE TG-Caustic system**



Source: RATE

Since its inception in 2011, Rameshni & Associates Technology & Engineering (RATE) has executed numerous projects around the world in sulphur recovery and gas treating. At the same time RATE has also been working hard to develop new technologies related to sulphur technologies, gas treating and overall total sulphur management to improve emissions for a better future and a cleaner environment. One of these developments is the RATE patented process scheme for super enhanced tail gas recovery (SETR), a zero emission tail gas process designed to achieve less than 10 ppmv of SO_2 from the stack.

Adding a caustic scrubber after the tail gas incinerator has become very popular in the USA, China and many other countries to achieve new emission regulations without any modification to existing units. With this system, the unrecovered sulphur compounds from any type of Claus unit and tail gas treating unit are routed to the incineration system where all the sulphur compounds are converted to SO_2. The amount of SO_2 depends on the overall sulphur recovery of the SRU/TGU. The SO_2 stream flows to the caustic scrubber, where SO_2 is absorbed in the caustic solution, and the flue gas, which is sulphur free, is vented to the atmosphere. RATE has designed several caustic scrubber systems known as the TG-Caustic system that are in operation.

The disadvantage of the caustic scrubber is the generation of a new waste stream, so-called spent caustic. The spent caustic contains absorbed SO_2 and needs to be disposed of safely or neutralised. In some facilities dealing with the spent caustic is a major issue. The spent caustic can be sent to the water treatment system if such a unit is available at the facility, another option is to collect the spent caustic in a tank and by bubbling air through the solution a chemical reaction takes place which neutralises the solution so that it can be safely disposed of without violating any environmental regulations. Another disadvantage of the caustic scrubbing system is that unrecovered sulphur compounds are wasted and disposed of.

Fig. 1 shows thermal incineration with the RATE TG-Caustic system.

SETR: an alternative to caustic scrubbing

RATE's new Super Enhanced Tail Gas Recovery (SETR) process is a type of tail gas treating system to recover SO_2 after the incinerator. The SETR reactors can be added to any type of Claus units, or to any tail gas treating units after the incinerator and before the stack and provides an alternative to caustic scrubber systems. The key advantage is that additional sulphur compounds are recovered and sent back to the sulphur plant. The SETR process is a cost competitive solution, it does not require any chemicals or solvents, it does not generate a waste stream, sulphur pit vent no longer needs to be routed back to the Claus unit and most importantly, the sulphur emission will be near zero. While the sulphur free flue gas to the stack may be a large streatm, the regenerated stream from the SETR reactor to the Claus unit is small and does not have any impact on the existing SRU (e.g. the hydraulics) and no modifications are required apart from the addition of a nozzle.

The SETR process recovers unconverted sulphur compounds mostly in the form of SO_2 in two switching SETR reactor beds. SO_2 is adsorbed in a cold bed SETR reactor, as a result the gas leaving the cold reactor to the stack is SO_2 free. The cold bed SETR reactor containing adsorbed SO_2 then switches to a hot bed SETR reactor where the adsorbed sulphur compounds are regenerated using a slip stream of air and a slip stream of acid gas to establish an adequate temperature. The gas stream containing the regenerated sulphur compounds leaves the hot reactor and is recycled to the thermal or catalytic section of the Claus unit.

The SETR reactors consist of hot and cold reactors equipped with 2 or 3 way motor switching valves. The acid gas stream to the cold SETR reactor is driven from the incinerator waste heat boiler where all the sulphur compounds are converted to SO_2. The SO_2 is adsorbed in the cold reactor and the flue gas, free of SO_2, is sent to the stack.

The SETR hot reactor receives a slip stream of the feed amine acid gas containing H_2S to the Claus unit plus a slip stream of air from the main combustion air blower. The regenerated stream from the hot SETR reactor is recycled back to the thermal or catalytic section of the Claus unit.

The SETR regeneration reactor operates at 320°C to 400°C to maximise the SO_2 regeneration to promote the Claus reaction.

The regeneration procedure accomplishes a number of chemical transformations. Most importantly, SO_2 is displaced by the hot gas. Sulphate and thiosulphate, which are present on the surface of the adsorbent, are reduced by H_2S in the regeneration stream of the amine acid gas. In addition, any oxygen which is adsorbed in the uptake cycle will be removed by reaction with H_2S.

The SETR process is not a sub-dew point process, where the bed become saturated with sulphur, rather, the SETR process has fixed bed reactors that are heated up and cooled down in a SO_2 adsorption-based Claus tail gas process. The adsorption mode operates at cold temperature to adsorb the SO_2.

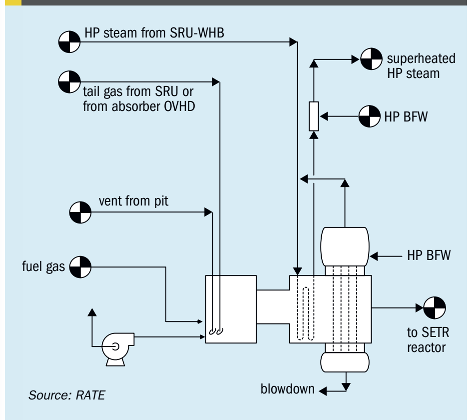
During the cold mode of operation, the SETR reactors contain components such as SO_2, $S_2O_3^{2-}$ and SO_4^{2-}. Suitable materials of construction are therefore selected to prevent any corrosion.

Sizing of the SETR reactor design is based on the adsorbent rate of SO_2, which in turn is calculated based on the SO_2 content and the required residence time.

Figs 2 and 3 show the SETR technology, which consists of adsorption and regeneration reactors located after the incinerator and before the stack.

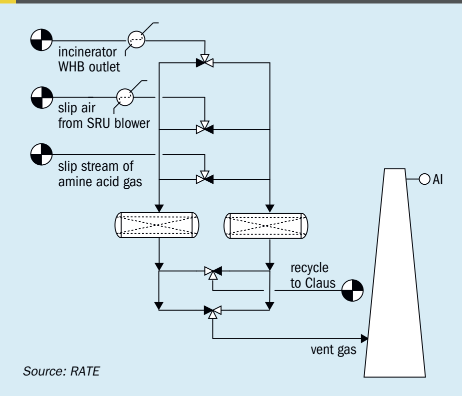
Adding SETR to a conventional SRU/TGU with a capacity of 100 t/d is estimated to add an additional 10% to the capital cost. The SETR process does not require any utilities or chemicals. The catalyst has to be replaced every four years, coinciding with the changing of the Claus catalysts.

Fig 2: **Incineration system**



Source: RATE

Fig 3: **SETR fixed bed reactors for SO_2 adsorption and regeneration**



Source: RATE

Case Studies

Case 1

RATE was contacted by a power plant facility in Asia which produces around 30-50 t/d sulphur. The incineration unit is a common unit for the sulphur recovery unit as well as other units throughout the plant. The gases containing sulphur compounds, including the stream from the sulphur recovery unit, flows to the main incinerator where all the sulphur compounds are

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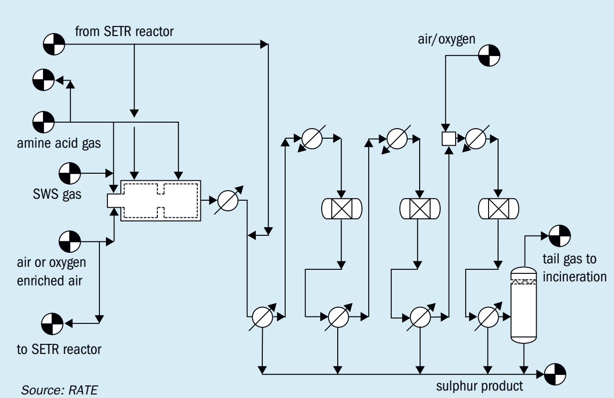
Fig 4: **SMAXB with SETR recycle to the reaction furnace**



Source: RATE

converted to SO_2. The outlet from the main incinerator is a very large flow representing the entire flue gas for the power plant.

The power plant currently employs the ammonia/ammonium sulphate method for desulphurisation, producing 7,000 to 8,000 tonnes of waste daily. As a result, the power plant has to spend $4 million per month to deal with the waste generated from the ammonium sulphate process in order to meet environmental standards. Therefore, improving the efficiency of the waste is the top priority for this facility.

In this application RATE has proposed to replace the ammonia/ammonium sulphate method for desulphurisation with SETR technology. The flue gas enters the adsorbent reactors and all of the SO_2 is adsorbed on the catalyst bed. The flue gas, now sulphur free, flows to the stack and the regenerated stream from the SETR regeneration reactor stream containing H_2S and SO_2 and sulphur compounds is recycled back to the existing sulphur plant.

The sulphur plant was evaluated for the addition of a recycle stream from the SETR unit and the existing sulphur plant was found to be capable of receiving such a stream. The regenerated stream is very small and does not have any impact on the existing units. The SETR unit will serve the entire power plant and will take a few months to build but will subsequently provide huge savings. If the SRU had its own incineration then the SETR unit would be much smaller. The power plant is pleased with the solutions and is planning to move forward with the SETR technology.

Case 2

RATE's US patented process known as SMAX and SMAXB is a sulphur recovery scheme to achieve up to 99.5% sulphur recovery without any tail gas treating unit. Existing Claus units can be upgraded to SMAX and SMAXB to increase the sulphur recovery with minimum capital cost.

In this process the catalytic stages consist of one or two Claus stages, the direct reduction stage and the direct oxidation stage. In the last condenser, the condensed sulphur is separated from the gas in a coalescer section that is integral to each condenser and fitted with a stainless steel wire mesh pad to minimise sulphur entrainment. The tail gas flows to the incineration system (Fig. 2) to convert all the sulphur components to SO_2. The combusted products are cooled and flow to the SETR tail gas treating process (Fig. 3) to achieve an overall sulphur recovery of close to 100%.

RATE proprietary catalysts are used in both the direct reduction and direct oxidation stages. The direct selective oxidation catalyst is supplied by a European catalyst manufacturer and the direct selective reduction catalyst, which was developed in the US, is supplied by a US catalyst manufacturer. These catalysts have been pilot tested for two years with very successful results.

The advantages of the new direct selective oxidation catalyst (SMAX) are:

- demonstrated ability to be regenerated in case of accidental poisoning;
- high activity and selectivity – not sensitive to water vapour content in the feed;
- activity and selectivity is maintained over a wide range of space velocity;
- higher catalyst activity means higher design space velocity and less catalyst volume;
- relatively low activation temperature allows operating up to 2% H_2S in the feed: unique advantage for oxygen enriched SRU;
- allows Claus unit to be operated at the optimal H_2S/SO_2 ratio design;
- not sensitive to H_2S/SO_2 ratio – provides process reliability, stability, and ease of control;
- provides high CO reduction efficiency which reduces stack gas CO emissions.

The advantages of the new direct selective reduction catalyst (SMAXB) are:

- targeted regenerated gas from regenerable flue gas desulphurisation processes and IGCC hot gas desulphurisation processes;
- more concentrated SO_2 stream than Claus process gas (10 to 30%)
- tolerance of high operating temperatures (300 to 600°C);
- tolerance of high space velocity (up to 15,000 h^{-1});

SMAXB units can be upgraded using oxygen enrichment because there is no temperature limitation. Accurate H_2S/SO_2 ratio control is not crucial to "S-MAXB" performance (off ratio is not critical). Existing 3-stage Claus or direct oxidation plants can be easily retrofitted to S-MAXB to increase recovery.

Combination of SETR with SMAX or SMAXB

When combining SETR with SMAX or SMAXB, the regenerated stream from the SETR process is recycled back to the SMAX or SMAXB process where near 100% recovery is achieved without using any conventional tail gas treating system. This scheme will reduce the capital and operating costs compared to a conventional SRU/TGU which requires many items of equipment, very high utility consumption in the tail gas treating section plus chemical solvent.

Fig. 4 shows SMAXB with the SETR recycle to the reaction furnace. The scheme includes one Claus stage, one selective reduction catalyst reactor and one selective direct oxidation reactor.

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Next issue: November/December 2017

- Fertilizers for soybean
- India's fertilizer industry
- Global nitrogen outlook
- Who's who in sulphuric acid revamping
- Phosphoric acid process choices
- Usolskiy get ready

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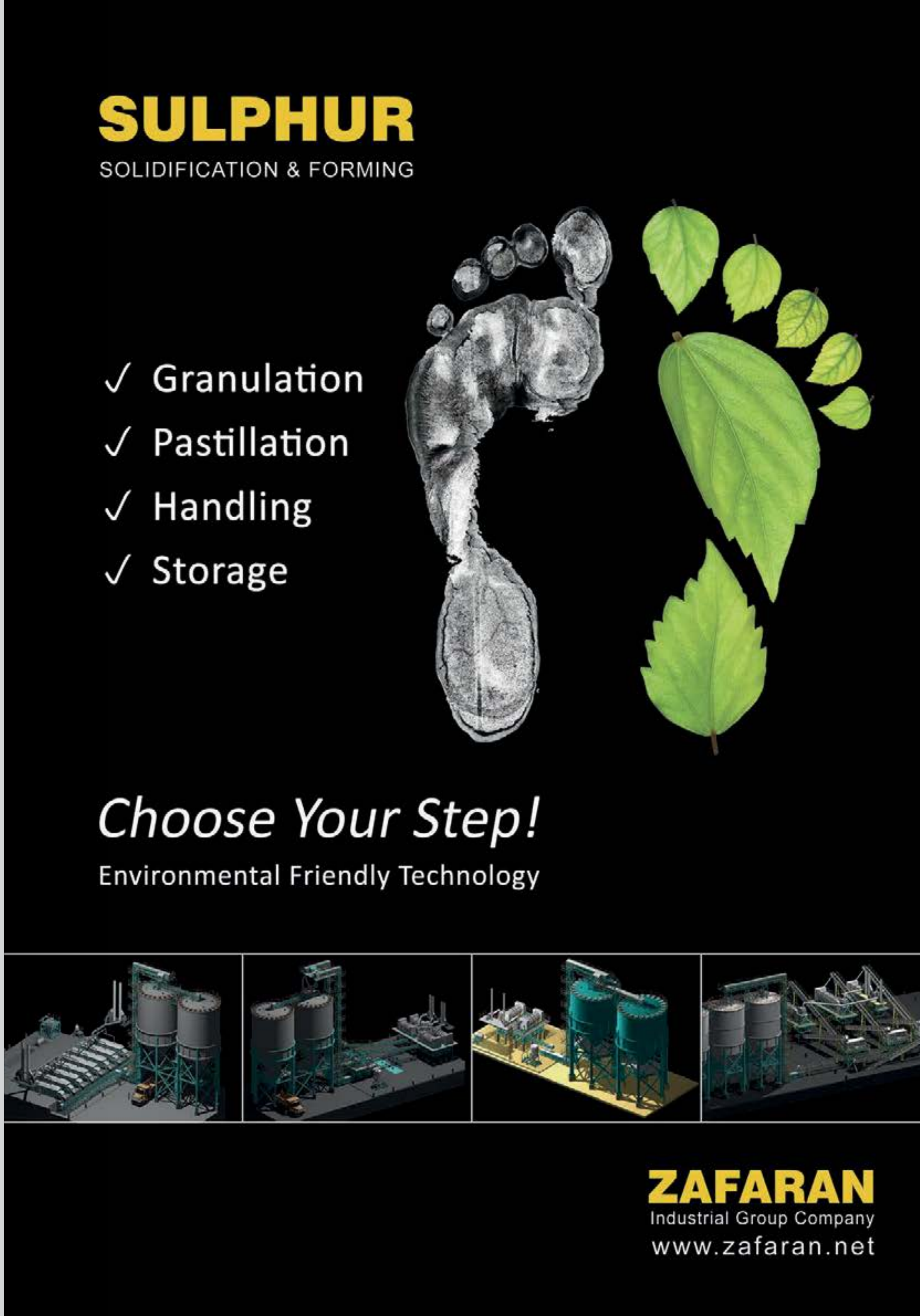

CONTENTS
What's in issue 372

COVER FEATURE 1
Sulphur 2017 Conference, Atlanta

COVER FEATURE 2
North America refining

COVER FEATURE 3
Wet ESP designs

COVER FEATURE 4
Sulphur recovery trends

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