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# SULPHUR

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**Cover:** *The Ha'penny Bridge, Dublin. Doram / iStockphoto.com*

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# Sulphur: commodity or by-product?


> **The economics of a project, and whether it is successful or otherwise, can occasionally turn on sulphur sales and logistics.**

When is a commodity a commodity, and when is it simply an inconvenient by-product? As far as elemental sulphur is concerned, the answer never seems to be a simple one, and it often comes down to the attitude of individual producers. Back in the 1970s and 80s, when sulphur production was predominantly via Frasch mining, and hence virtually all production was voluntary, then sulphur was of course seen as a commodity. But as involuntary production, from processing of sour oil and gas, has come to represent almost all sulphur production, so the question has become a more vexed one.

Some of the difference, no doubt, simply comes down to pricing. After all, when sulphur prices reach levels of $800/t and more, as they did very briefly during the price spike of 2008, then everyone sits up and takes notice, and it becomes very much a co-product rather than a by-product. Equally, when sulphur is being sold at essentially zero cost, once transport and storage rates are taken into account, then anyone could be forgiven for regarding it as merely an extra burden that has to be dealt with. Volume can also be a major deciding factor in how the substance is viewed. An oil refiner, dealing with multiple product streams, is relying for the bulk of their income on selling large volumes of diesel and gasoline and other higher value liquids, and associated cheap bulk solids like sulphur and petroleum coke, which must be stored and sold if the refinery is to keep operating, might often seem like more of a nuisance by comparison, especially when the sulphur is only being extracted and produced because legislation forces the refiner to remove it from finished products, and to remove it down to increasingly (sometimes exasperatingly) low levels.

But sulphur does have a value, at the end of the day, and the economics of a project, and whether it is successful or otherwise, can occasionally turn on sulphur sales and logistics. This is especially true where sour gas production is concerned, and the question of whether sulphur is a commodity or a by-product occurred to me most recently during a visit to Abu Dhabi for the Middle East Sulphur Conference. Because for ADNOC, at least – the Abu Dhabi National Oil Company – sulphur is very definitely a commodity. Now, arguably, when you are producing thousands of tonnes per day of sulphur, then you are forced to have to spend more time thinking about it, simply as a commercial necessity. Nevertheless, according to ADNOC, who explained their philosophy during the opening commercial session on 'unlocking the sulphur value chain', attention to detail at every step of that chain can pay dividends, from sulphur recovery, through forming and handling, to marketing and shipping. The aim is to deliver a premium quality product to the end-consumer, and this involves everything from controlling the temperature of the Claus furnace to ensure destruction of benzene, toluene and xylene (BTX) to control of dust formation through careful handling, to moisture control during and post-granulation according to client requirements; while the granules may exit the former at 0.5% moisture, in the heat of summer this can fall to as low as 0.2% by the time it reaches the port at Ruwais, necessitating careful monitoring and dosing of surfactant and water to keep dust levels low. Monitoring and sampling is carried out at the granulator and on loading and unloading each train car, as well as at dockside and when loading vessels, and careful attention is paid to cargo holds to ensure that these are clean and treated and that excessive moisture does not lead to acidification on what can occasionally be long voyages, say to South America. It is an impressive set-up, and shows what can be achieved by a producer determined, as ADNOC put it, to regard sulphur as a valuable product in and of itself, and to "go the extra mile" in ensuring its quality.

*Richard Hands, Editor*

# Price trends

**MARKET INSIGHT**

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

## SULPHUR

### Short term stability

Sulphur prices for major benchmarks remained firm from the new year through February. While signs of stability were reflected in Middle East prices, firming sentiment in China has continued to buoy the market. The temporary stalling of market activity during the Lunar New Year in China was expected to lead to a softer footing, but the spot market in China remained firmly above $100/t c.fr in mid-February. With the global supply/demand balance is expected to remain stable in the first half of 2017, this has added to producers' bullish outlook for the short term. However, the challenges of the processed phosphates market remain a question mark, although market sources indicate a floor may have been reached for DAP prices. Signs of slightly higher pricing in finished fertilizer prices may provide support for sulphur to remain stable at recent achieved prices.

All eyes were on Middle East producers for January/February to see if the bull run would continue. Overall, prices remained stable, with some slight downward adjustments. Adnoc announced a price of $92/t f.o.b. Ruwais for the Indian market for February, unchanged on January levels but up on its December price. In Qatar, Tasweeq posted its price at $88/t f.o.b. Ras Laffan for February, also flat on its January price. Meanwhile Aramco Trading in Saudi Arabia announced a decrease for February, down by $2/t on January to $88/t f.o.b. Jubail. It remains to be seen if increases will be posted for March/April but developments in China will be a key indicator, particularly if prices remain above $100/t c.fr. Any softening below this level will lead to further price erosion for exporters.

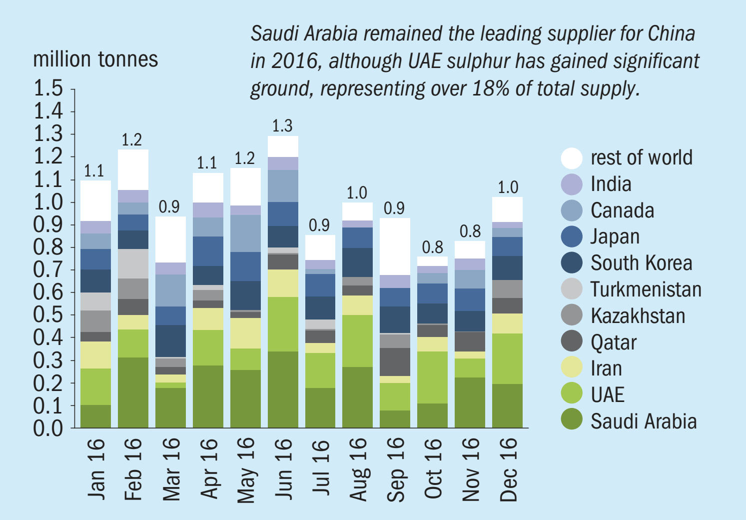
A key focus for the sulphur market in 2017 is developments across supply, with two major projects set to tip the market balance significantly, if capacity rates are achieved. In Qatar, the RasGas Barzan project is set for another restart, with sulphur from both phases adding around 800,000 tonnes at capacity. Over in Kazakhstan, the Kashagan project is also expected to have sulphur cargoes available from around Q2.

Inventory levels of sulphur at the major ports in China dropped down to around 1.4 million tonnes in January-February, with further erosion expected to add to the more stable to firm outlook for market pricing. However, as seen in 2015, inventory levels can often disconnect with pricing. Inventories averaged around 1 million tonnes throughout 2015 and prices fluctuated with correlating to this perceived low level of stocks. Spot prices in mid-February edged up to $100-105/t c.fr based on business from the Middle East but a question mark remains on whether this can continue. China sulphur import levels are also a key consideration for the market, due to the size of its demand. Annual imports in 2016 were flat on 2015 levels at just under 12 million tonnes. Monthly trade through 2017 will be an important indicator for demand in China. Saudi Arabia remained the leading supplier for China in 2016, with trade up by 6% year on year. The market share of UAE tonnes showed an increase of 18% – reflecting the shift in trade since the start-up of the Shah gas project. At the same time, Iran and Kazakhstan's shares showed decreases, down by 28% and 61% respectively. Looking ahead, the rise of oil and gas projects in the China domestic market may impact import levels, leading to displacement of supplier tonnes to alternative markets.

Spot prices in the Indian market have also remained firm in three digits at around the mid-$100s/t c.fr in February. There have been some limitations to spot interest as Iffco started its planned turnaround at its Paradeep facilities at the start of February, due to run until the start of March. During this month, processed phosphates production will be down. The change in scheduling from April to February for this maintenance is a reflection of the lacklustre phosphates market. Next interest in the spot market for Iffco is not expected until April due to contract commitments and the reduction of demand. PPL was in discussions for a contract for 250,000-300,000 tonnes of sulphur in February with a supplier. The rise of Indian refining capacity has also added competition to imported sulphur, with some buyers preferring to purchase tonnes from local producers.

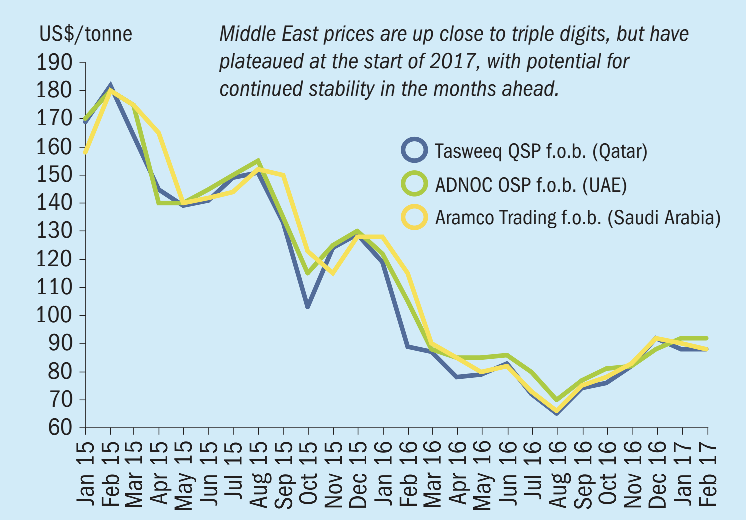
Brazilian sulphur imports for 2016 showed a 7% decline on 2015 at just

**Fig 1: China monthly sulphur imports, 2016**




Source: Integer, GTIS

**Fig 2: Middle East producer sulphur prices, Jan 15 to Feb 17**




Source: Integer, ICIS

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1.8 million tonnes. While shipments from the US saw a 9% rise, trade from Russia, Kazakhstan, and Canada decreased. The slowdown in phosphate demand led to the decline. In January 2017, imports show a 4% year on year increase but still remain below 2015 levels. Russian tonnes dominated while there was a significant decline from the US. Spot prices in Brazil have also firmed into the $100s/tonne c.fr, with a March/April shipment heard fixed at $104/t c.fr from Vancouver. However, fresh business was expected to be concluded below this level.

Supply in North America was heard balanced to tight. US sulphur production continued to show improvement through 2016. Supply in 2017 is expected to remain stable. Vancouver pricing firmed into the $90s/t f.o.b based on increases in key end user markets. US Gulf export prices also firmed, into the $80/t f.o.b. Trade in North America is also expected to continue to shift, with the potential for Mosaic to ramp up utilization rates at its 1 million tonne per year sulphur remelter.

## SULPHURIC ACID

### Stable market

The start of 2017 has been a stable period for the sulphuric acid market for the most part. In NW Europe, prices have remained flat at $5-15/t f.o.b. based on business to Morocco and Brazil. Smelter acid producers remained comfortable through to February, with steady contract liftings the main focus. The limited producer turnaround schedule in Europe in 2017 may add some bearish sentiment should spot cargo interest fail to materialise in key end user markets. Atlantic Copper has a scheduled maintenance but other producers have yet to announce plans following the heavy schedule in 2016.

Morocco continues to be a major talking point for the acid market, following the surge in imports in 2016. The temporary disruption to trade at Jorf Lasfar Port was resolved at the start of February. For the month of January, acid imports remained strong at 179,400 tonnes, while February arrivals were pegged much lower. OCP's purchasing strategy for the year ahead of direct acid is as yet unclear, but volumes placed in the market are key to balancing acid due to the absence of Cuba this year. Spain is expected to remain at the helm for acid trade to Morocco but new supply sources such as Canada and the Philippines may also feature.

At the start of February South Korean suppliers were still negotiating contracts for shipments to India, with outstanding contract cargoes from 2016 still moving. Price ideas in North East Asia firmed in line with international developments and balanced supply positions but remained at negative netbacks of €5/t f.o.b. Producers were heard seeking positive netbacks in any new business. LS Nikko was planning a month long turnaround at its Onsan II smelter at the end of February, adding to the more balanced tone to the market. Trader Tricon was understood to have settled a 100,000 tonne contract with Korea Zinc. Japanese producers also remained balanced through to February, with commitments covering surplus acid through the first half of 2017. In October, Pan Pacific Copper was heard planning a two month maintenance at its Saganoseki smelter.

The Brazilian market continued to firm into February, with deals heard up in the high $40s/t c.fr. However, acid trade in January reflected a 12% decline year on year, with Sweden leading as the main supplier. Activity in Brazil could help support the market, but competition from surplus acid in Mexico remains a concern.

US acid demand has been lacklustre in early months of 2017, with local supply heard balanced. The spate of maintenance turnarounds in North America is expected to lead to firmer price ideas for any spot volumes, providing a potential outlet for European volumes. Freeport McMoRan will also have a planned turnaround, scheduled for April. Vale is expected to reduce production ahead of its April turnaround. Kennecott Utah Copper is set to undergo a turnaround through May 2017, leading to a loss of around 80,000-90,000 tonnes. ■

# Price indications

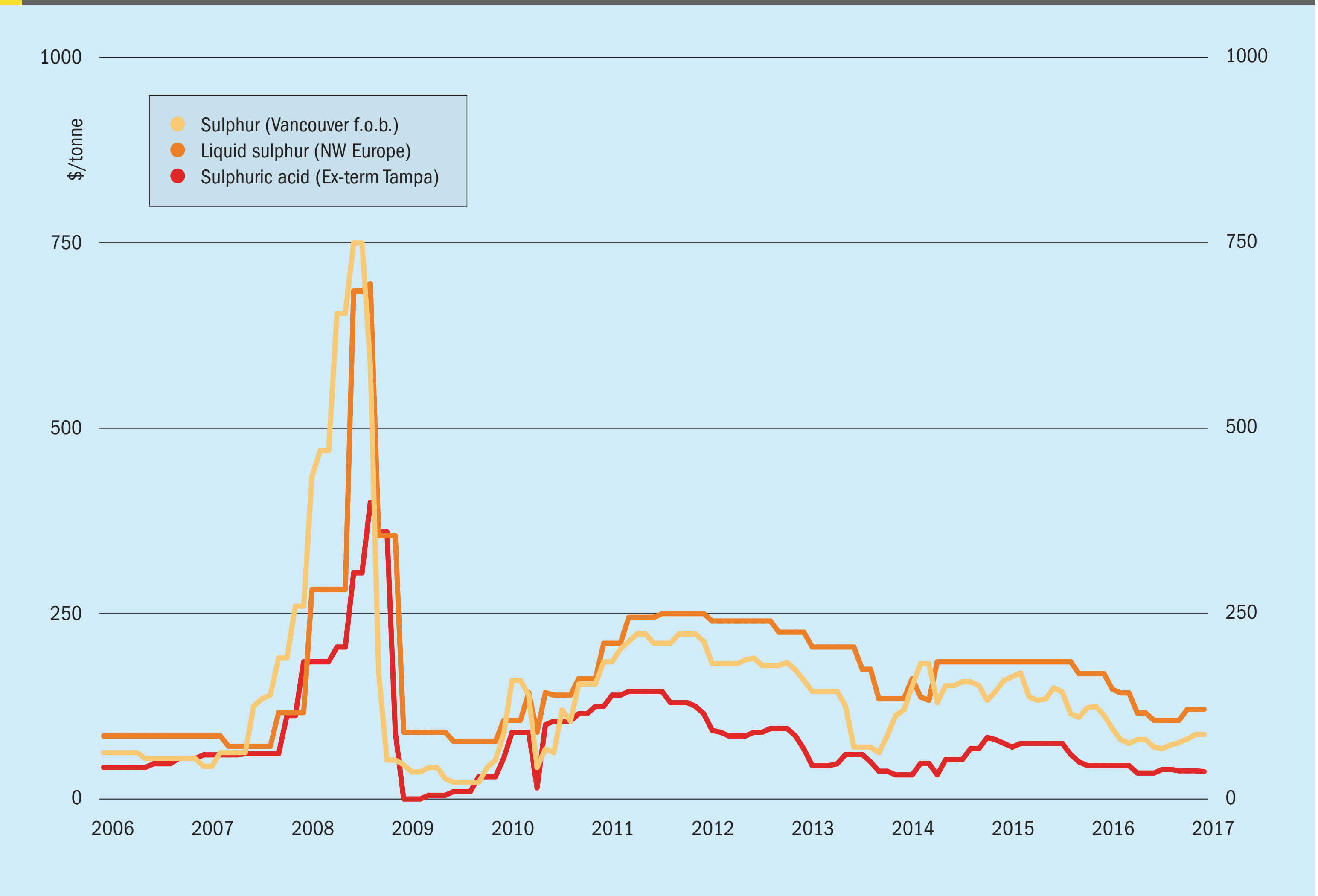
Table 1: **Recent sulphur prices, major markets**

| Cash equivalent | August | September | October | November | December |
|---|---|---|---|---|---|
| **Sulphur, bulk** ($/t) | | | | | |
| Vancouver f.o.b. spot | 68 | 73 | 76 | 81 | 87 |
| Adnoc monthly contract | 70 | 77 | 81 | 88 | 92 |
| China c.fr spot | 77 | 83 | 97 | 100 | 101 |
| **Liquid sulphur** ($/t) | | | | | |
| Tampa f.o.b. contract | 65 | 65 | 70 | 70 | 70 |
| NW Europe c.fr | 106 | 106 | 106 | 121 | 121 |
| **Sulphuric acid** ($/t) | | | | | |
| US Gulf spot | 40 | 40 | 38 | 38 | 38 |

*Source: Various*

# Market outlook

**Historical price trends** $/tonne




*Source: BCInsight*

## SULPHUR

- Fresh sulphur supply from Kashagan in Kazakhstan and Barzan in Qatar is due online in 2017. At capacity, both projects combined will add almost 2 million tonnes of supply to the export market. Developments at this projects will be a crucial factor for the market balance in the coming months.
- Monthly trade to China will be a key indicator for sulphur demand. The progress of oil and gas projects in the domestic market could lead to shifts in the market balance, and potential its import levels.
- Brazil imports may improve in 2017, January data already reflects a 4% increase year on year, but still remains 15% below 2015 levels. Improved import demand would help to support firmer US Gulf prices.
- Higher commodity pricing and a more positive outlook for metals provides some support for growth in the outlook for sulphur demand in the non-fertilizer sector. However, a sustained period of higher prices will be needed to restore projects previously stalled or cancelled.
- **Outlook:** Sulphur prices are expected to remain stable in the high $80s/t f.o.b. Middle East if China continues to purchase spot volumes around $100/t c.fr. The slight improvement in the processed phosphates market may lend support to a more stable short term outlook. The latter part of 2017 is likely to see downward pressure however due to the expected start-up of key projects.

## SULPHURIC ACID

- Morocco will remain a major factor to support the European acid market this year. Trade in January was strong but whether this will continue remains in question.
- Competition from Mexico in tenders in Brazil could prove a strain on the market, depending on the surplus availability from the El Boleo mine.
- Brazilian acid imports will be an important outlet for producers following the lacklustre trade in 2016. January data shows a year on year drop of 12% but remain on a par with 2015 levels, with Sweden the leading supplier. Developments in the processed phosphates market and improved demand could boost trade this year.
- The market balance in North America is expected to see pockets of tightness due to the number of planned maintenances at smelter, potentially adding some support to the spot market.
- **Outlook:** Demand in Morocco, Brazil and the US will be critical to supporting the stable outlook for the acid market in the coming months. Acid prices are expected to hold at current levels in Europe due to the balanced position of producers. In Asia, some firming is possible into positive values for spot due to the planned turnarounds and contract commitments. The market will need to balance volumes no longer being exported to Cuba, with Morocco expected to be the leading market absorbing diverted tonnes.

# Sulphur Industry News

## CANADA

### Statoil exits oil sands business

Norway's Statoil has said it is exiting Canada's oil sands with the sale of assets, as it continues efforts to streamline its portfolio. The state-owned firm is selling its Kai Kos Dehseh oil sands assets to Athabasca Oil for C$832 million (US$617 million) in cash and shares, it said in a statement. The deal, which closed on January 1st, 2017, is still subject to certain regulatory approvals, the company said. The assets being sold include the producing Leismer steam-driven project and the undeveloped Corner lease. There are also several midstream contracts associated with Leismer, according to Statoil, which had a 100% interest in the project in northern Alberta. The deal includes a C$435 million (US$323 million) cash consideration and a further C$147 million (US$109 million in shares in Athabasca.

"This transaction corresponds with Statoil's strategy of portfolio optimisation to enhance financial flexibility and focus capital on core activities globally," said Statoil's executive vice president for international development and production, Lars Christian Bacher. Statoil says that within Canada it will now prioritise developments offshore of Newfoundland and Labrador.

Statoil entered the oil sands business 10 years ago via its acquisition of North American Oil Sands in 2007. In 2011 a subsidiary of Thailand energy giant PTT Exploration and Production PLC bought a 40% stake in the project, and then in 2014 the two companies divided the asset into their respective interests. The purchase boosts Athabasca's total production capacity to roughly 40,000 bbl/d, up from the current 24,000 bbl. The Leismer and Corner project have both been approved for 80,000 bbl/d expansions, Athabasca said. "This transaction is transformational for Athabasca and establishes scale with top tier thermal assets and people," Robert Broen, Athabasca's president and CEO, said in a statement. "We are pleased to have Statoil, a global energy leader, as an investor in the Company."

## CHILE

### Fluor awarded refinery project in Chile

Fluor Corporation has been awarded a contract by Empresa Nacional del Petróleo (ENAP) for the engineering, procurement and construction of a new process unit at ENAP's Biobío refinery in Chile. Fluor booked the contract for an undisclosed sum in 4Q 2016. Fluor will install a new flue gas steam generator, a wet gas scrubber and purge treatment unit to treat residual gas generated in the refinery's fluid catalytic cracker to reduce air emissions. Fluor is also responsible for interconnections between the new and existing unit, which will occur during a schedule-driven 2017 turnaround.

"We leveraged our extensive Chilean experience, strong relationships with local contractors and our global refining expertise to develop the construction-driven execution plan that meets the client's requirements," said Mark Fields, president of Fluor's Energy & Chemicals business in the Americas.

"While Fluor has been active in Chile for more than 35 years, this project is significant for us as it marks our entry into the oil and gas market in Chile," said Andrés Beran, Fluor's vice president of sales for Latin America. "We look forward to making this project the first of many to be executed for ENAP in the coming years."

## UNITED KINGDOM

### IMO hopes for "smooth and effective" move to 0.5% sulphur

The International Maritime Organization's (IMO's) Sub-Committee on Pollution Prevention and Response (PPR) held its fourth session on January 17th in London, at which it laid out plans for work the committee will undertake in 2018 and 2019 to support what it describes as a "smooth and effective" 2020 implementation of a global 0.50% sulphur cap on marine fuels.

"Inconsistent and ineffective implementation would increase the uncertainty concerning actual market demand for 0.50 percent sulphur marine fuel oil, which in turn would increase the difficulty for the marine fuel oil supply chain to plan effectively to meet global demand and for ship operators to assess the viability of investing in exhaust gas cleaning systems," said PPR. "Importantly, ineffective implementation is likely to lead to more ships using non-compliant fuel oil so having a significant commercial advantage over ships complying, leading to a distortion in the market."

PPR says its scope of work will include consideration of the preparatory and transitional issues in implementing the new cap, the impact on fuel and machinery systems that may result from the use of fuel oils with a 0.50% sulphur limit, verification issues and control mechanisms and actions required to ensure compliance and consistent implementation. The sub-committee will work to develop a draft standard format for reporting fuel oil non-availability, as well as guidance to assist Member States and stakeholders in assessing the sulphur content of fuel oil delivered to ships.

## FRANCE

### Axens completes Heurtey takeover

Axens says that it has achieved a "successful outcome" regarding its tender for the shares of Heurtey Petrochem. A total of 2,374,874 Heurtey Petrochem shares were bought between December 1st, 2016 to January 5th, 2017. At the settlement date Axens held, in concert with IFP Investissements, a total of 4,144,659 shares and 4,219,159 voting rights of Heurtey, representing 84.33% of the share capital and 83.55% of the voting rights. Axens, part of the Institut Francais du Petrole (IFP) Group, is an international provider of advanced technologies, catalysts, adsorbents and services, focused on the conversion of oil, coal, natural gas and biomass to clean fuels and production and purification of major petrochemical intermediates. Heurtey Petrochem is an international oil and gas engineering group covering two market segments: process furnaces for refining, petrochemicals and the production of hydrogen; and the processing of natural gas through its subsidiary Prosernat. In this sector, Heurtey operates in both EPC engineering and as a technology licensor.

## INDONESIA

### Indonesia walks out of OPEC over production cuts

Indonesia has suspended its membership of OPEC in the wake of the new targeted production level of 32.5 million bbl/d, 1.2 million bbl/d down on the previous produc-

PHOTO: GOVERNMENT OF KAZAKHSTAN

*Atyrau Refinery, Kazakhstan*

tion target, and the first cut in OPEC output in eight years. Indonesia had only re-joined the cartel in December 2015, after an absence of seven years, and in spite of having been a net oil importer since around the turn of the millennium. However, since 2013, when state-owned Pertamina's production fell to 200,000 bbl/d (less than 25% of the country's total), it has been ramping production back up again, and reached 310,000 bbl/d in 3Q 2016.

## KAZAKHSTAN

### Kashagan ramping up production

North Caspian Operating Company (NCOC), the joint venture which runs the giant Kashagan Caspian oil and gas project, says that it is now ramping up production at the field to a capacity of 180,000 bbl/d, following the resumption of output in September last year. Plans for Kashagan Phase 1 to reach its targe production capacity of 370,000 bbl/d depend on associated (sour) gas reinjection to start up and be optimised, according to NCOC. NCOC is a joint venture between Exxon, Shell, Eni, Total, CNPC, and Japan's Inpex, along with Kazakh state oil company Kazmunaygaz.

The giant Kashagan field, which is believed to contain up to 13 billion barrels of recoverable oil, has so far has absorbed $50 billion. It belatedly began operations in 2013, but production was suspended within weeks as sour gas leaked from corroded pipelines. An inspection showed that the entire 200-km line from the artificial island that serves as a base for the drilling rigs to the onshore gas processing system needed to be replaced because of micro-cracking. Production resumed in October 2016 at a rate of 90,000 bbl/d. At the end of last year, NCOC said that it had obtained approval to begin early engineering and design work for further expansion of Phase 1 production at Kashagan, which could increase Phase 1 capacity to 450,000 bbl/d.

### Atyrau Refinery to build new SRU

Work has begun on a new sulphur plant at Kazakhstan's Atyrau Refinery, one of the largest refineries in the country. It forms part of a three phase modernisation programme which began several years ago in 2008, and which was originally due for completion in 2015. On completion, the project will enable the refinery to increase crude oil refining capacity to 5 million t/a and produce fuels which conform to Euro-5 standards. The Atyrau Refinery was first commissioned in 1945 with an initial capacity of 800,000 t/a and processes heavy crude oil with a high paraffin content, from oil deposits in the western regions of Kazakhstan. It was uprated in the 1960s and again in the 1980s to 4.3 million t/a, and currently has a throughput of 100,000 bbl/d. The third and final phase of the expansion project is adding new fluid catalytic cracker units, as well as additional sulphur recovery. The new Claus unit has a capacity of 58 t/d. Sulphur output in 2014 was 2,450 tonnes, according to operator KazMunaiGaz.

Kazakhstan plans to complete modernisation of all three of its major refineries by 2018, Modernization of the Pavlodar oil and chemical plant is scheduled for completion in 2018 at a project cost of $700 million. The reconstruction and modernisation of the Atyrau refinery is scheduled for completion in July 2017 at a final cost of $2.05 billion. Modernisation and reconstruction of the Shymkent refinery is also planned to be completed in 2017, at a cost of $2.04 billion.

## ABU DHABI

### Practical gas conditioning presentations dominate SOGAT 2017

Sour field development plans are ongoing throughout the Middle East, given the gas demand and none more so than in the UAE where priorities in ADNOC's integrated gas master plan includes tapping into deep and sour gas reserves, improving the processing capacity of the Al Hosn Shah plant by 50% and deploying innovative carbon capture, utilisation and storage (CCUS) for enhanced oil recovery. These issues will be a focus of the SOGAT Conference programme, which will also include presentations of sour processing projects in Egypt, Oman and Saudi Arabia. Sessions will focus on reducing project costs and risks, improving energy efficiency. In processing plant, operational safety issues in real time, practical solutions for overcoming SRU operational problems, CCUS future and current regional plans and effective contaminant removal case studies. There are also five pre-conference workshops on Sour Oil & Gas Process Optimisation; Amine Treating; Improving SRU Cost Efficiencies and Associated KPI's; Benefits of Hybrid Solvents for Mercaptan in Natural Gas; and CCUS.

## IRAN

### New gas processing capacity

The Iranian Oil Industries' Engineering & Construction Group (OIEC) is working on units to collect associated gas drilling sites in the west of Iran, and is aiming to end flaring at four oil fields by 2020. Around $1.55 billion is being spent on the NGL-3100 project, which will receive 270 million cfd of associated gas. When up and running in 2020, it will produce 1,170 bbl/d of sour gas condensate, 74 million cfd of sweet gas, 105 million cfd of light sour gas as well as 42,000 bbl/d of ethane to supply feedstock to petrochemical complexes.

Meanwhile, in the northeast of the country, Iran has prioritised development of the Tous gas field, the second upstream gas project after Khangiran in the country's north-east. The decision to move ahead with Tous comes after Turkmenistan has cut the supply of gas to Iran in a dispute over gas price and take or pay terms. Tous has reserves estimated at 60 bcm of sour gas, and Iran aims to produce 4 million $m^3$/d of gas from the field. Currently the only field producing in the region is Khngiran, which has an output of 48 million $m^3$/d. Iran doubled gas imports from Turkmenistan in 2015 to 9 bcm, but according to the agreement between the two countries, it should have imported 14 bcm. During a period from 2006 to 2016, Iran imported about 74.35 bcm of Turkmen gas, according to the Iranian Oil Ministry.

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**SAUDI ARABIA**

## Ma'aden announces third phosphate project

The Saudi Arabian Mining Company (Ma'aden) has announced plans to expand its phosphate business via a third major phosphate fertilizer project. The target date for completion of the new phosphate project is 2024, by which time Saudi Arabia will have increased its capacity and hence potential supply to global markets by 3 million t/a to a total of nearly 9 million t/a of phosphate fertilizer products. Ma'aden says that the expansion is part of the Saudi Vision 2030 goal of economic diversification, which seeks to broaden the base of Saudi Arabia's economy away from the kingdom's traditional reliance on oil and petrochemicals.

No further details of the new project other than the headline figure of 3 million t/a are yet available, aside from a projected cost of $6.4 billion, and Ma'aden says that the project is still subject to completion of feasibility studies and consents. The company is currently in the process of completing its second world-class phosphate venture; the $8 billion Wa'ad Al Shamal Phosphate Company, a joint venture between Ma'aden, Sabic and Mosaic. The joint venture has already started producing ammonia, while its remaining plants, including DAP and MAP, are expected to start production in 2017, reaching a capacity of 2.9 million t/a of phosphate. The company's first project, the Ma'aden Phosphate Company, a $5.6 billion joint venture between Ma'aden and Sabic, began operations in 2011 and has 2.9 million t/a of phosphate capacity, at it is likely that the new project will be similar to this first, fertilizer-focused one (the second project focused instead on industrial and purified phosphates). Saudi Arabia's phosphate reserves, situated in the north of the country near the Jordanian border, amount to around 7% of the world's total.

"Ma'aden will continue to develop global partnerships and grow its presence across the phosphate value chain to ensure that a variety of high quality Saudi phosphate fertilizer products are delivered to international markets" said Ma'aden president and CEO Khalid Al-Mudaifer. "We intend to reinforce Ma'aden's position as a reliable contributor to the world's food security, meeting farmers' growing demand for high quality soil nutrients at the right time and place", he added.

### Ma'aden inks supply agreement with Bangladesh

The Saudi Arabian Mining Company (Ma'aden) has signed a phosphate fertilizer supply contract with the Bangladesh Agricultural Development Corporation (BADC). Under the terms of the contract Ma'aden will supply di-ammonium phosphate fertilizer (DAP) for the year 2017. BADC is a government-owned corporation which imports fertilizers under the umbrella of the Bangladesh Ministry of Agriculture.

Speaking at the contract signing ceremony in Ma'aden's Riyadh headquarters, Khalid Al Rowais, Senior Vice President of Ma'aden's Phosphate Business Unit, said "we are pleased to once again offer quality, reliable fertilizer supplies to Bangladesh. We hope to demonstrate our ongoing commitment to the Bangladesh Ministry of Agriculture and the BADC by continuing to build on our long term relationship for many years to come."

**CHILE**

### SNC-Lavalin awarded EPC contract for acid plant

Corporación Nacional del Cobre de Chile (Codelco), one of the world's largest copper producers, has appointed SNC-Lavalin to construct two sulphuric acid plants at the Chuquicamata copper smelter complex, located in the Antofagasta region of northern Chile. Codelco's project incorporates sulphuric acid production technology by MECS, a wholly owned subsidiary of DuPont, with whom SNC-Lavalin has successfully executed projects for more than 50 years. The plants, which will produce up to 2,048 t/d of sulphuric acid, will treat off-gas from the Chuquicamata smelter. These new plants will replace those currently in operation at the facility and are part of Codelco's ongoing environmental compliance plans. Construction is expected to begin in early 2017 with SNC-Lavalin providing basic and detailed engineering services, procuring equipment, and constructing the acid plants through their Santiago and Toronto offices.

"Following our recent contract award for the replacement of the effluent treatment plant at the Chuquicamata copper smelter, this new contract again supports our strong position in Latin America", noted SNC-Lavalin mining and metallurgy president José J Suárez, adding that the company was proud to be part of a project that would be a key element in Codelco's future environmental programme.

"Codelco's environmental values are closely aligned with those of SNC-Lavalin and this adds to an already excellent working relationship," he concluded.

**KAZAKHASTAN**

### Uranium production to fall in 2017

Kazatomprom has announced a 10% cut to planned uranium extraction in Kazakhstan this year in response to a glut in global supply. Kazakhstan has become the world's largest uranium producer, responsible for around 40% of global output, with production rising rapidly from 2,200 tonnes U308 in 2001 to 23,800 tU308 in 2015. Full figures for 2016 are not yet available, but had been targeted at 24,800 tonnes U308. Kazatomprom chairman Askar Zhumagaliyev says that the company will cut output this year by 2,000 tonnes compared to 2016, equivalent to a 3% cut in the global supply of uranium.

"While the outlook for nuclear energy growth continues as strong as it has done in many years, the realities [are that the] near-term uranium market remains in oversupply," Zhumagaliyev explained. "These strategic Kazakh mineral assets are far more valuable to our shareholders and stakeholders being left in the ground for the time being, rather than adding to the current oversupply situation."

Over the past five years, the price of uranium has more than halved from $50/lb to around $20/lb per pound, owing to a cutback in nuclear generation in Japan and a ramp up in output at some mines, including Canada's massive Cigar Lake deposit.

Leaching of uranium has become a major use for sulphuric acid in Kazakhstan.

**IRAN**

### Outotec to deliver two acid plants

Outotec has agreed with National Iranian Copper Industries Company (NICICO) on the delivery of two sulphuric acid plants for the Sarcheshmeh and Khatoon Abad copper smelters in Kerman Province. The value of the orders is approximately euro 50 million, according to Outotec, and has been covered by a confirmed letter of credit and booked in Outotec's Q4/2016 order intake. Outotec's scope of delivery includes engineering, main process equipment and instrumentation for the acid plants as well as spare parts and supervisory services for installation and commissioning. Outotec's deliveries will take place in mid-2018.

"We are pleased to complement our earlier deliveries of Flash Smelting technology for NICICO's two copper smelters with modern Outotec off-gas cleaning systems and sulfuric acid plants. With these investments, the smelters will have full compliance with the latest environmental standards", says Kalle Härkki, head of Outotec's Metals, Energy & Water business unit.

## AUSTRALIA

### FQM fined for 2014 acid spill

First Quantum Minerals has been fined A$40,000 for a 2014 incident at the Ravensthorpe nickel plant. FQM Australia Nickel, a subsidiary of Vancouver-based First Quantum Minerals, entered a guilty plea to a charge of failing to provide a safe working environment, when a tank containing sulphuric acid ruptured in December 2014. A spill of pproximately two million litres of sulphuric acid slurry initially trapped three workers in a nearby control room before they escaped without injury. The spill damaged infrastructure, including critical electrical equipment which cut the power supply to the entire site, 540 kilometres south-east of Perth. The accident closed the mine for 49 days, and the atmospheric leach circuit for the High Pressure Acid Leach (HPAL) plant was inoperable for around seven months. Sulphuric acid for the leaching process is produced on-site in a 4,400 t/d sulphur burning, double absorption acid plant.

## PERU

### Outotec to provide filtration plant for Toquepala

Southern Copper Corp has selected Outotec to deliver a concentrate filtration plant for the Toquepala concentrator expansion in Southern Peru under a contract worth more than €15 million. Outotec's scope of delivery includes the engineering and supply of a filtration plant consisting of automatic pressure filters, ancillaries and control as well as related installation supervision and commissioning services including spare parts. The equipment and services will be delivered mostly during the second half of this year. The expansion is expected to increase the annual production capacity by 100,000 t/a of copper.

## ZAMBIA

### BMR hopes to recover vanadium from tailings leach

BMR Group says it could potentially recover vanadium from the tailings generated by the Kabwe lead and zinc mine in Zambia to allow the production of vanadium pentoxide, adding a third commodity and possible revenue stream. The Kabwe mine operated over nine decades between 1904 and 1994, when the operation was shut down by previous owners after becoming uneconomical, and during this time produced a total of 1.8 million tonnes of zinc, 800,000 tonnes of lead, 80,000 kg of silver, 235,000 kg of cadmium and 7,816 tonnes of vanadium oxide. Since 2008, the mine has been steadily acquired by BMR, which now owns all the surface rights to the 705 hectare site. It is aiming to commission its treatment plant in the middle of 2017, using a sulphuric acid leach to initially process 5 t/h of ore, taking 573,458 tonnes of tailings from the wash plant graded at 10.66% zinc and 7.21% lead. Operating expenditure is currently estimated to be $120/t of tailings treated. Around 50% of this will be spent on acquiring the sulphuric acid needed for the treatment process. BMR plans to obtain its supply from local smelters where prices are close to historic lows.

## INDIA

### Sunset review on phosphoric acid 'dumping'

The Directorate General of Anti-Dumping Duties (DGAD) has begun a sunset review of anti-dumping duties imposed on imports of phosphoric acid from Israel and Taiwan. Since October 2011, duties of $116.25-$260.26 per tonne have been imposed, with definitive anti-dumping duties imposed from April 4th, 2012, expiring on January 12th 2017. Based on an examination of the petition filed by the domestic industry the High Court of Delhi has initiated a review from the producers/exporters involved in the manufacture or sale of phosphoric acid of all grades and concentrations (excluding agricultural/fertilizer grade). The injury investigation period covers the period April 2012 – March 2015.

## DEMOCRATIC REPUBLIC OF CONGO

### Leach project debottlenecking complete

Tiger Resources says that achieved production of 23,119 tonnes of copper cathode at its Kipoi facility during 2016. The company says that it has also completed reinforcement of the intermediate leach solution pond, allowing production at Kipoi to be resumed at nameplate operating levels. The company will embark on the construction of an additional pond after the wet season. The company has also completed the debottlenecking capital works programme to expand the Kipoi plant's nameplate production capacity to 32,500 t/a. The coffer dam, a smaller dam contained within the larger dam that comprises the new tailings storage facility, has also been commissioned. This programme provides sufficient capacity to allow full production through the new tank leach facility for the duration of the wet season. Laying of the HDPE liner to the larger tailings three dam surface has been deferred until the dry season.

## UNITED STATES

### Settlement for PPA plant

Innophos Holdings, Inc. says that it has entered into a settlement with the US Environmental Protection Agency (EPA), and Louisiana Department of Environmental Quality (LDEQ) to address concerns regarding manufacturing processes at its Geismar, Louisiana purified phosphoric acid (PPA) facility. As part of the settlement, Innophos will pursue implementation of "deep well injection", allowing the company to continue its current PPA operation in Geismar, while satisfying outstanding environmental concerns raised in 2008 by the government.

Kim Ann Mink, chief executive officer of Innophos, commented, "We are committed to supporting our phosphoric acid customers' needs and believe that the terms of this settlement position us to be able to do so by securing the long-term viability of our Geismar PPA plant. We believe that the agreed upon solution addresses all environmental concerns with minimal effect on our business and operations."

Joshua Horenstein, Vice President and Chief Legal Officer of Innophos, added, "While we stand behind our long-term assertion that our operations at the Geismar facility are in full compliance with all applicable federal and state laws and regulations, this negotiated solution is fair for the public and the Company. As a company committed to environmental protection at our facilities, we are glad to address all of these alleged issues at our Geismar facility by proactively working with the government."

Innophos recently received a permit from the Louisiana Department of Natural Resources to begin construction of its deep well injection system, which began in late 2016 and is expected to be completed by early 2018.

### Better numbers for leach project according to developer

Taseko Mines Ltd says that recently completed technical work on the Florence Copper Project has resulted in a significant improvement in project economics. Russell Hallbauer, president and CEO of Taseko, said: "In addition to the permitting milestones achieved over the past months, we are very pleased with the outcome of the latest engineering work, which has increased the net present value of the project to $920 million. Contributing to the higher NPV is an 11% increase in average annual copper production, combined with slightly lower operating costs and pre-production capital. With annual copper production of 81 million pounds (36,800 metric tonnes) and pre-production capital of $200 million, Florence Copper is one of the least capital intensive copper projects in the world. Two important parameters for any copper leaching process are copper recovery and acid consumption," continued Mr Hallbauer. "The copper recovery estimate of 70% from the 2013 technical report as well as the acid consumption estimate have both been confirmed with the more detailed testing."

### Approvals for Idaho phosphate mine

The US Bureau of Land Management (BLM) and US Forest Service have separately given their approval to an open put phosphate mine planned by Canadian fertilizer manufacturer Agrium Inc. The BLM manages the area where the mining will occur, while the Forest Service manages land that will receive waste materials. The expected life of the new Rasmussen Valley Mine is just under eight years, and will guarantee 1,500 mining jobs in the state, which contains one of the largest US deposits of phosphate. Simplot and Monsanto also operate mines in the area. Agrium has struck a deal with Monsanto to take waste rock from the new mine and dispose of it in a pit at a nearby Monsanto mine now going through the reclamation process.

### Licensing deal on acid scrubbers

DuPont subsidiary Belco Technologies Corporation has signed an agreement with Lundberg LLC to collaborate on the supply of air pollution control systems on an exclusive basis around the world (except China). The partnership applies to air pollution control systems for refining and petrochemical plants, as well as coke calciners associated with refining and petrochemical plants, and is valid for 10 years. Under the new agreement, Lundberg will exclusively offer its Geoenergy E-Tube wet electrostatic precipitator (ESP) technology as part of BELCO scrubbing system, while BELCO will solely use Lundberg Wet ESP in its scrubbing systems for the noted industries. BELCO will act as prime contractor for these projects with Lundberg as subcontractor. The scrubbing systems clean flue and exhaust gases and reduce emissions, particulates, SOx and NOx, as well as minimising other pollutants and sulfuric acid mists, enabling refineries and petrochemical plants to meet emission controls and clean air regulations while staying in continuous operation.

"The partnership with Lundberg allows both of our companies to offer refineries and petrochemical plants air pollution control systems with proven, reliable technology, thereby leaving refiners and petrochemical plant operators free to focus on production instead of worrying about emissions control and compliance," said Edward Hutter, applications manager, BELCO. "This agreement is a sign of the faith and trust we have in each other's technical capabilities and systems."

## SYRIA

### Iran signs deals over phosphate mines

Although civil war continues to rage in Syria, president Bashar Assad's strategic partner Iran is continuing to sign commercial deals, including a license for a mobile phone operator, the transfer of 5,000 hectares for the creation of a gasoline terminal and the right to operate the phosphate mines at Sharqiya, approximately 50 km south of the ISIS-held ancient city of Palmyra.

## EGYPT

### Sun Group plans to set up phosphate plant in Egypt

Indian trading and consultancy company Sun Group says that it plans to set up a phosphate plant in Egypt, at a cost of $40 million. The plant to be set up in cooperation with Phosphate Misr and other Egyptian companies, and follows a meeting between Sun Group CEO and founder Vikramjit Sahney and Egypt's Minister of Trade and Industry Tarek Kabil. The phosphate plant will be established in the el-Seba'eia area of Aswan in Upper Egypt. Both parties are reported to be discussing a memorandum of understanding to begin work on the project during 2017.

## TUNISIA

### Phosphate output continues to be below target

According to data from the Gafsa Phosphates Company (CPG), phosphate production reached 3.66 million tonnes in 2016, 45% lower than the company's target of 6.6 million tons. CPG Information Officer Ali Houchati said continuing social protests at the mines were responsible for the reduction in output, which blocked production activities for four months in 2016 at Mdhilla, whose two production units accounts for 20% of the company's capacity. CPG says that most (2.6 million tonnes) of its 2016 output came from the four washing units in Metlaoui and Kef Eddour, while production at Redeyef did not exceed 126,000 t/a. For 2017, CPG aims to produce 7 million tonnes of commercial phosphate, with the acquisition of new transport and production equipment, in addition to recruitment programs.

## CANADA

### Arianne looking at cooperation with Rio Tinto

Arianne Phosphate, which is developing the Lac à Paul phosphate mining project in Quebec, says that it has agreed a new deal with Rio Tinto to explore the potential of sharing maritime services. Under the terms of the agreement, both companies will engage in further discussions about the prospective use of common carriers for transporting Arianne Phosphate's products to international markets. It is expected that this will offer the company cost savings and efficiency improvements. Ariane CEO Jean-Sébastien David also stressed that such an agreement would also help minimise the environmental impact of its Lac à Paul project.

### Potash Ridge secures acid supply

Potash Ridge Corporation says that is has signed a five year agreement with "a major North American supplier" for 100% of the company's sulphuric acid requirements at its planned Valleyfield Project in Quebec. Valleyfield is a planned 40,000 t/a potassium sulphate ('SoP') fertilizer production facility, which will utilise the proven Mannheim Process, reacting sulphuric acid with potassium chloride.

"This supply agreement secures the supply and price of our second largest raw material input cost for the long-term," said Guy Bentinck, president and chief executive officer. "The next steps to constructing Valleyfield will be permitting, finalising the $50 million financing requirement, and securing SoP off-take agreements, all of which are expected in early 2017."

This five-year agreement is effective upon commencement of Valleyfield's operations. Construction is scheduled to start in early 2017, with commissioning anticipated 9-12 months after the start of construction. Valleyfield's production of SoP will serve the growing market for low-chloride fertilizers for a wide variety of fruits, vegetables, and other chloride intolerant crops in eastern Canada and throughout the US eastern seaboard.

## CHINA

### Sinopec selects alkylation technology

The China Petrochemical Corporation (Sinopec) has awarded DuPont the license and engineering contract for its *STRATCO*® alkylation technology. The new unit is to be located at the existing Sinopec Tianjin (TPCC) refinery in the Tianjin Binhai New Area district. The sulphuric acid alkylation unit will improve the quality of the existing refinery gasoline pool to ensure compliance with the China V standards. Construction of the new 7,700-bbl/d alkylation unit is expected to begin in early 2017 with TPCC aiming for start-up by late 2017 or early 2018. TPCC is the largest oil refiner in northern China with primary crude oil processing capacity of 15.5 million t/a. Along with the license and engineering package, DuPont also will provide proprietary equipment and operator training/commissioning assistance for the alkylation unit.

Kevin Bockwinkel, global business manager for *STRATCO*® technology said, "We look forward to working with Sinopec and TPCC and enhancing our strong relationship with the addition of an alkylation unit at Tianjin. The new unit will enable the refinery to produce clean fuel safely and reliably while improving the overall gasoline pool quality. We value Sinopec's commitment to utilising best-in-class technology"

DuPont has licensed a total of more than 850,000 bbl/d of *STRATCO*® alkylation technology capacity at 90 units worldwide.

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# People

The Saudi Arabian Mining Company (Ma'aden) has announced the appointment of its president and CEO **Khalid Al Mudaifer** to the Board of the International Fertilizer Industry Association (IFA). The IFA is a non-profit organization that represents the global fertilizer industry on issues related to the promotion of plant nutrients, improvement of the operating environment of member companies and the collection and compilation of industry information.

"For many years the IFA has been the voice of the global fertilizer industry, it plays a critical role in promoting industry issues and sharing best practices but it also sets the global standard for the study of our industry," said Khalid Al Mudaifer. "We have been growing our relationship with IFA for a number of years now, while continuing to establish our own credentials in the global phosphate fertilizer market."

Khalid Al Mudaifer has been President and CEO of Ma'aden since 2011 and has 30 years of industrial experience in executive positions in mining-related sectors. He joined Ma'aden as Vice President for Phosphate and Business Development where he led the early development of the Ma'aden Phosphate Company ($5.6 billion) and the master planning of Ras Al Khair Industrial City ($28 billion). As a result of projects developed by Ma'aden and its partners, Saudi Arabia is now the world's third largest exporter of phosphate fertilizer.

**Adel Hattab** has been appointed executive vice president, Strategic Customers and Business Development and a member of the executive board of Outotec as of April 1st, 2017. He has been in the Executive Board since 2014, first as head of the Europe, Middle East and Africa (EMEA) region, and, since February 2016, as head of the Markets unit. As EVP, Strategic Customers and Business Development, Hattab will lead the development of strategic customer relationships, sales processes and customer experience as well as marketing and market intelligence operations globally.

**Olli Nastamo**, currently responsible for Outotec's Strategy, Marketing and Operational Excellence, will as of April 1, 2017 lead the Operational Excellence organisation. Nastamo continues to report to CEO Markku Teräsvasara as member of the Outotec Executive Board.

Applied Analytics has announced that **Dale Langham** has joined them as VP of Sales for North America & the Caribbean. Dale his 37 years' experience in the industry, from his early days as an instrument specialist at Exxon to, most recently, Director of Sales for Schneider Electric's Process Automation division. He has experience with a wide variety of process analysis technologies, playing an integral role in the success of FTIR products at Yokogawa, Gas Chromatography products at Emerson, and Tunable Diode Laser products at SpectraSensors.Applied Analytics says that they are "extremely grateful to have Dale come aboard with his experience and his incredible track record." Their domestic sales team has been restructured with Dale at the helm, driving their efforts to better serve customers.

Itafos has announced the appointments of **Mhamed Ibnabdeljalil** and **G. David Delaney** to the board of the company effective from December 31, 2016 and February 6, 2017, respectively. The company has also announced the appointment of **Marten Walters** as vice president of Operations, effective from January 16, 2017. Itafos says that the appointment of seasoned industry leaders to its management team expands its expertise and provides it with deep insight as it continues to move forward with the development of its business plan. In their new board positions, Dr. Ibnabdeljalil and G. David Delaney will provide governance best practice, strategic guidance and overall counsel to the Itafos management team. As Vice President of Operations Mr. Walters will oversee all aspects of the company's physical operations.

"Itafos is very pleased to announce the expansion of the board and management team of the company and to strengthen its industry expertise with this strong executive leadership," said Brent de Jong, Chairman of the board of Itafos. "All three individuals have extensive industry experience and demonstrated track records of driving profitable growth and transforming businesses."

Itafos also announced that **David Andrew Parsons** will be resigning from the board effective on February 6, 2017 to allow for the appointment of Mr. Delaney. Itafos confirmed that Mr. Parsons will continue to serve the company in an advisory role.

## Calendar 2017

### MARCH

**12-15**

Phosphates 2017, TAMPA, Florida, USA
Contact: CRU Events. Tel: +44 20 7903 2167
Email: conferences@crugroup.com

**9-21**

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

**26-30**

SOGAT 2017, ABU DHABI, UAE
Contact: Dr Nick Coles, Dome Exhibitions
Tel: +971 2 674 4040
Email: nick@domeexhibitions.com

### APRIL

**24-26**

TSI World Sulphur Symposium,
DUBLIN, Ireland
Tel: +1 202 331 9660
Email: sulphur@sulphurinstitute.org
Web: www.tsi.org

### MAY

**9-12**

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

### JUNE

**9-10**

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

### OCTOBER

**9-11**

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

### NOVEMBER

**6-9**

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

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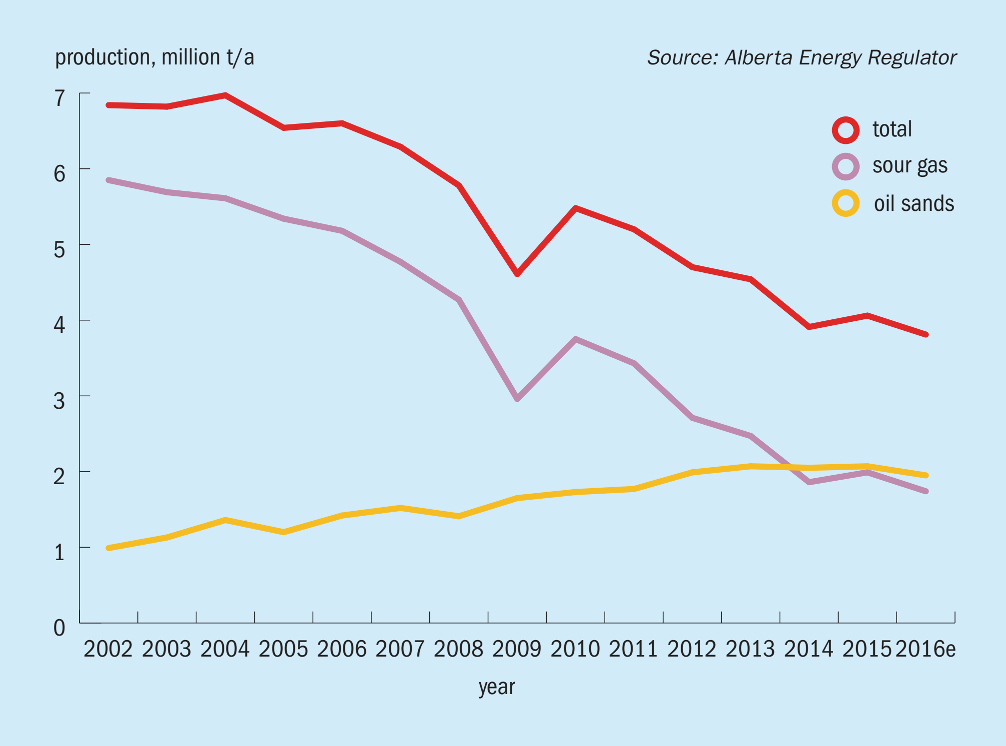
# Canadian sulphur forming projects

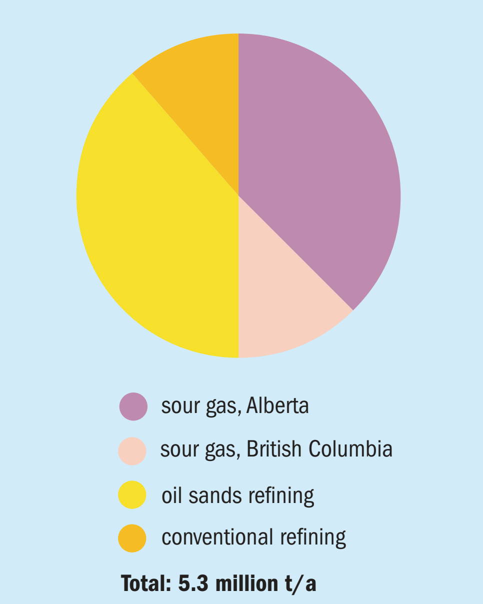
The changing nature of the US sulphur market is having a knock-on effect north of the border, where an industry that previously concentrated on liquid sulphur transport is now turning to new forming capacity.

Fig 1: **Alberta sulphur production, million t/a**




*Source: Alberta Energy Regulator*

Fig 2: **Canadian sulphur production, 2015**




*Source: CNRL, AER, Argus*

Canada has long been one of the largest exporters of sulphur in the world, but that position has been eclipsed in recent years by the rise of new producers in the Middle East, particularly Qatar and Abu Dhabi, at the same time that falling production from sour gas is reducing Canadian sulphur availability. This sea change in the global sulphur market has led North America's largest consumer of sulphur, Mosaic, to install a new 1 million t/a sulphur melter at its New Wales site to allow it to use solid sulphur imports from overseas, as discussed in our article last year (*Sulphur* 365, Jul/Aug 2016, pp22-24). This has the potential to reduce US consumption of molten sulphur from Canada, posing an additional headache for Canadian sulphur producers. The response has been for Canada to look to new sulphur forming projects in order to give itself the option of sending more solid sulphur overseas.

## Sulphur output

Canada's sulphur comes from three main sources: sour gas processing in Alberta and, to a lesser extent British Columbia; oil refineries, mainly in the east of the country; and upgrading of oil sands bitumen, virtually all of the latter in Alberta.

### Sour gas

Canada was one of the pioneers of sour gas extraction and processing, and especially of sulphur recovery from it, beginning in the 1930s in Alberta. Canada became the world's largest sulphur exporter on the back of its sour gas industry, extracting 7 million t/a of sulphur in the 1970s, most of which was exported. Moves to end flaring of sour gas boosted sulphur recovery in spite of falling output from maturing gas fields in the 1990s, and in its peak year of 2004, Canada exported over 8 million tonnes of sulphur. However, gas production in Alberta peaked in 2001, and during the 21st century Canada's sour gas production began to decline ever more rapidly, especially during the current decade as the US shale gas boom has undercut the economics of sour gas production.

Figure 1 shows the decline in Alberta sour gas production over the past decade and a half, from nearly 6 million t/a at the turn of the millennium to less than 2 million t/a today. While there has been some rise in sulphur output from oil sands processing, it has not been enough to offset the decline in sour gas production, and as a result overall Canadian sulphur production has fallen from about 9 million t/a in 2000 to less than 5.5 million t/a in 2015.

## Refineries

Canada operates 1.97 million bbl/day of refinery capacity, much of it in the east of the country. Ontario, Quebec and the Atlantic coast (Labrador, Newfoundland, New Brunswick) have 1.35 million bbl/d of capacity between them, or about two thirds of the total. Canada's refinery capacity is relatively small because most of its oil is exported to the US, rather than being refined in Canada. However, the rapid growth of cities in the west of Canada such as Vancouver and Calgary alongside refinery closures in the region has exposed the lack of refining capacity there, and led to shortages of refined products and large scale imports from the US and elsewhere. This in turn has prompted the development of new refinery capacity. However, the changing nature of the Canadian oil industry means that this new capacity is likely to be based on oil sands bitumen.

## Oil sands processing

Few refineries can process bitumen, so in order to reach a wider market the recovered bitumen must be upgraded to produce usable lighter fractions. Steam (in the case of in situ extraction) or hot water (for mined oil sands) are used to separate the bitumen from the sand. The bitumen is then heated and sent to drums where excess carbon (in the form of petroleum coke) is removed, and the superheated hydrocarbon vapours from the coke drums are sent to fractionators where the vapour condenses into naphtha, kerosene and gas oil. The end product is synthetic crude oil ('syncrude'), which can be shipped to refineries across North America. Currently around 40% of mined oil sands bitumen is upgraded, and Alberta has 1.2 million bbl/d of upgrading capacity. However, the bitumen can also be diluted with lighter fractions such as naphtha to produce a 'dilbit' (dilute bitumen) or even with syncrude to create a 'synbit'. These are light enough to be pumped, and so can be exported by pipeline or rail instead – around 60% of the oil sands production is exported in this way, much of it to be processed in the US.

Oil sands typically contain about 4-5% sulphur by weight, and therefore upgrading or refining it recovers significant tonnages of sulphur. As Figure 1 shows, Alberta oil sands upgrading capacity has been slowly rising, generating 1 million t/a of sulphur in 2002 and around 2 million t/a at present. However, upgrading capacity has been expensive and so there has been a preference to export the dilbit/synbit instead. But this has in turn been complicated by a lack of pipeline capacity.

A variety of new pipelines have been proposed to carry syncrude and dilbit either south to the US, east to the refineries of eastern Canada, or west to the Pacific for onward export to China. The most discussed has been the Keystone XL link to take bitumen from northern Alberta, across North America, to be processed on the US Gulf Coast. The section just south of the Canadian border was blocked by US environmental concerns and became a cause celebre in the US for most of the Obama administration. There are signs that the Trump administration will look to revive this project, but in the meantime, while large volumes were carried to the US by rail, here too there is a maximum capacity and lack of ability to get the bitumen to market – coupled now with the fall in global oil prices – has helped put a brake on new oil sands development.

In the absence of Keystone, other projects have come to the fore, including the Northern Gateway pipeline running west to the coast, with a proposed 500,000 bbl/d refinery at Kitimat at the end of it. However, only one proposal has actually begun construction, and that is the new C$8.5 billion refinery being built by the North-west Redwater Partnership at Sturgeon, northeast of Edmonton. This will be able to upgrade 80,000 bbl/d of bitumen in the first phase, due for completion in 2017,

Fig 3: **Sulphur in western Canada**


### Sulphur forming facilities

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

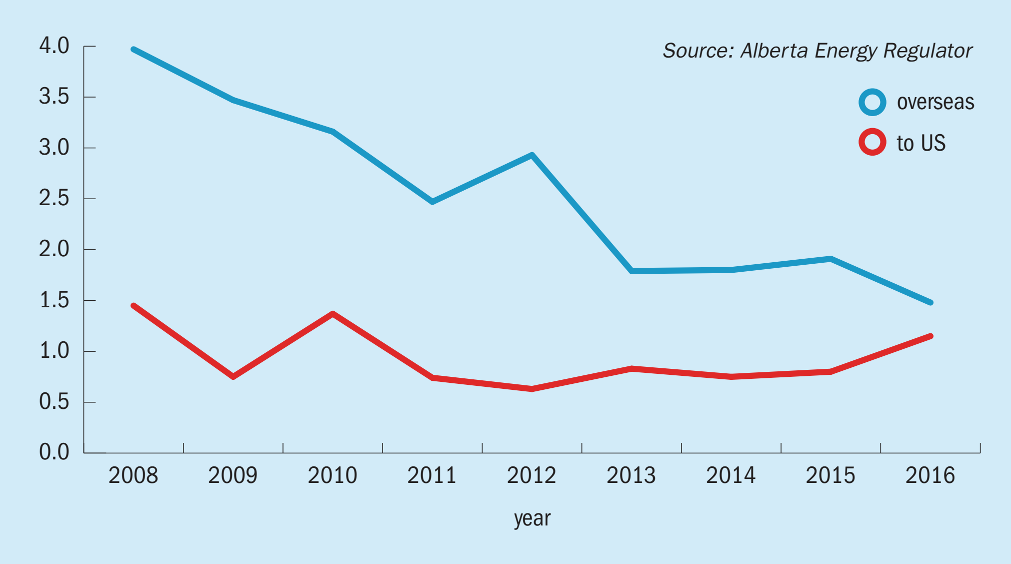
**British Columbia**

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

**New/proposed**

12. Heartland Sulphur
13. Oxbow (Lynton)

Fig 4: **Alberta sulphur exports, million t/a**




and will have similar capacity in two further phases slated for later development.

## Sulphur exports

Canada's sulphur production was about 5.3 million t/a in 2015, comprised of 2 million t/a from oil sands processing, 600,000 t/a from other refinery outputs, 2 million t/a from sour gas processing in Alberta and 650,000 t/a from sour gas in British Columbia (Figure 2). Canadian sulphur consumption, meanwhile, runs at about 725,000 t/a, leading to a surplus of 4.6 million t/a, most of which is exported. In 2015, around 1.9 million t/a was exported south to the US as molten sulphur, while 2.7 million t/a was exported via Vancouver port, mainly as solid sulphur. In addition to this, there are also significant sulphur stockpiles in northern Alberta, especially at Syncrude's production facilities near Fort MacMurray. Total Canadian sulphur inventory stands at over 11 million tonnes, 10 million tonnes of which is represented by Syncrude. There was considerable stock drawdown at sour gas plants during the 2000s, so virtually all of the stockpile is now in the oil sands patch.

Overseas, sulphur is generally marketed on a dry bulk basis. In order to move product to the port and participate in overseas markets, Canadian sulphur producers must have access to sulphur forming facilities. The US sulphur market, which imports a significant amount of Canadian sulphur, operates on a liquid sulphur basis because of the logistics infrastructure available. So Canadian sulphur producers must have access to a liquid rail car loading facilities to access the US sulphur market.

The cost of delivering Canadian sulphur to offshore markets was and is relatively high compared to other sulphur exporting countries, because of logistics and transportation issues. As Figure 3 shows, Canadian sulphur forming plants are comparatively far inland from the coast; the gas processing plants of Alberta and British Columbia are on average 1,400km from Vancouver. The terrain between the plants and the coastal terminals is also quite mountainous, with few roads or rail lines, while winter temperatures of -40 and snowfalls can complicate matters further. But this is dwarfed by the distances that sulphur must travel to reach US markets, with the principal consumers being in the Florida phosphate belt. This means that sulphur from Alberta reaching Florida has already travelled several thousand kilometres and attracted up to $120/t in transport costs. As noted above, this is what has driven Mosaic to build its own sulphur remelter at New Wales to handle solid sulphur from overseas.

> **"The cost of delivering Canadian sulphur to offshore markets was and is relatively high.**

Figure 4 shows Alberta sulphur exports over the past decade. While these have declined with the fall in sour gas production in the province, as can be seen it is mainly the exports via Vancouver which have declined, while the liquid sulphur shipments across the border to the US have declined relatively much less. However, the prospect of a reduction in liquid sulphur demand from the US means that producers set up to supply liquid sulphur must now consider alternative means of shipping and marketing their sulphur.

## Heartland Sulphur

The first major response to the situation has been the development of the Heartland Sulphur project, run by Heartland Sulphur LP, jointly owned by Lion Sulphur Inc, a wholly-owned subsidiary of sulphur transporter and marketer Petrosul International Ltd, and Inter-Chem Canada, part of the Oklahoma-based fertilizer marketing and distribution company the International Chemical Company. Petrosul began life over 40 years ago as a marketing vehicle for sour gas sulphur from producers in British Columbia, in much the same way that Cansulex – later Prism – was in Alberta.

Heartland is being developed in Strathcona County, northeast of the city of Edmonton, Alberta. The site is in the Industrial Heartland development area alongside a CN Rail line, providing shipping access to Vancouver ports, and also has access to Highway 15 for connection to producers in the oil sands, Edmonton, and surrounding areas. The facility will comprise a 2,000 t/d (650,000 t/a) sulphur forming and liquid sulphur loading facility. It is configured to receive up to 4,000 t/d of liquid sulphur from trucks, with the ability to increase receiving capacity if needed. On site working volumes include a 5,000 tonne liquid sulphur storage tank and a pad capable of holding 30,000 tonnes of solid product to allow for continued operations during logistical interruptions. The terminal can load solid and/or liquid rail cars for export to Vancouver or the US on the adjacent rail line.

Heartland says that its aim is to provide sulphur forming and transloading facilities for producers across the oil sands patch as well as other gas production and refining capacity in Alberta, offering flexibility to form and ship as dry bulk or as liquid sulphur, and thereby access either the US market – which functions mainly on liquid sulphur – or overseas export markets, which mainly use dry cargoes. It also has its eye on the 10 million tonnes of sulphur in block form in the northern oil sands, which could potentially be re-melted for sale. Heartland expects to process around 600,000 t/a of sulphur, $^2/_3$ of it as prills for overseas export and one third as molten sulphur for shipment to the US.

Heartland has chosen the Devco Wet-Prill process as the forming technology for the facility. The company says that this



1 47 2 48 3 49 4 50 5 51 6 52 7 53 8 54 9 55 10 56 11 57 12 58 13 59 14 60 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46

offers operational advantages, including reduced dust generation, high safety and reliability, and proven marketability. Molten sulphur is pumped onto perforated trays which direct the sulphur in narrow streams into an agitated water bath. Prills form as the sulphur comes in contact with the water and these are separated from the water with a vibrating screen and transferred to the conveyor loading system. Water is recycled through the system to minimise water use and environmental impact. The fresh prills are transferred directly into rail cars under normal operating conditions, which helps maintain product quality and minimise dust generation.

The environmental permitting process was finally completed in November 2016, and Heartland is now moving forward with construction of the facility, which is expected to be completed in mid-2017, with start-up of operations soon afterwards.

## Lynton

The other major forming project under discussion is an expansion of Oxbow's Lynton sulphur handling facility. Oxbow – the brainchild of Koch brother Bill Koch – began life in 1983 as an energy and bulk handling company, but during the 2000s sold its energy portfolio and moved into transport and marketing of petroleum coke and coal. In 2011 it entered the global sulphur industry through the purchase of the International Commodities Export Corporation (ICEC), and in 2013 it acquired the remnants of the interests of the Prism Sulphur Corporation in Canada. Prism was itself the trading and marketing arm of a consortium of mainly Alberta-based sulphur exporters, and had originated in a 1991 reorganisation of Cansulex – the Canadian Sulphur Export Consortium.

Lynton is a site already used by Oxbow, next to a rail line 17km southeast of Fort MacMurray in northern Alberta, and zoned for industrial use. The proposal was to add 2,500 t/d of solid sulphur forming capacity, equivalent to about 800,000 t/a, using pastillation technology, as well as upgrading the existing sulphur trans-loading capacity of the site. The process was expected to be low-odour and low $H_2S$ generating, with dust suppression systems and a thermal oxidiser to destroy odour, and the entire sulphur forming process enclosed within a building; the finished pastilles would be stored in enclosed silos. However, Oxbow's application for an environmental permit was nevertheless rejected in 2014, and for the moment the Lynton expansion plan remains in abeyance.

## Evolution or revolution?

In spite of the start-up of Mosaic's melter, no seismic shift in the US sulphur market was visible during 2016. Canada remained the dominant source of sulphur imports, and while figures to November show a decline in US imports from Canada this year, to the tune of about 350,000 tonnes, this has not been made up for in a significant increase in imports from elsewhere. The fires in Alberta which disrupted oil sands production have impacted on Canadian sulphur output, while low prices in the phosphate industry actually persuaded Mosaic to idle some of its capacity in Florida for part of the year. So far the change to the North American sulphur market looks to be more evolution than revolution.

# Saudi Arabia: beyond oil

PHOTO: SSSCCC/ISTOCKPHOTO.COM

Saudi Arabia's 'Vision 2030' plan to diversify its economy could radically transform many industries within the country, including the way that it produces and consumes sulphur.

*Oil – no longer the mainstay of the Saudi economy?*

After half a century of relying on a single substance, oil, Saudi Arabia appears to be making a serious effort to diversify its economy. While the current fall in oil prices – driven in no small measure by Saudi Arabia's refusal to play its usual role as swing producer – has been one factor in this, there are also many other reasons why the country is seeking to end what one minister has called its oil "addiction". The changing nature of the oil market is certainly one – the US is no longer the major oil importer that it once was as tight oil released by fracking techniques makes the USA almost self-sufficient in oil production once again. There is also the potential return of Iran to producing and selling larger volumes of oil, and expanding production in e.g. Russia at the same time that the Chinese economy has matured and shifted away from its rapid industrialisation. All of this has produced the current glut of oil and in spite of the recent deal between OPEC and other major producers there seems to be no real prospect of oil prices returning to the levels of more than $100/bbl seen only a couple of years ago.

But Saudi Arabia must also contend with major structural and demographic changes of its own – it has a young and rapidly growing population, and must find jobs for its young people. The unemployment rate in Saudi Arabia is officially 12%, but this rises to 28% among young people, and the government is widely suspected of massaging the figures. And even when new jobs are created, they are not going to Saudis – it is reckoned that 95% of new jobs created in 2016 went to non-Saudis. At the same time, GDP growth has been feeble – only 0.8% year on year between 2003 and 2013, well below the levels of other developing economies. Oil revenue – running at 80-90% of the government's funds – has allowed Saudi Arabia to run a virtually zero-tax economy and still provide social benefits, but this, it is argued, has merely 'tranquilised' the population, reducing incentives and entrepreneurship.

At the same time, the current run of low oil prices has brought home to the government that it cannot continue spending as it has. While the country has huge reserves of cash, it has already managed to spend $150 billion of them in just 18 months. This is not a sustainable situation.

## Vision 2030

The response of the Saudi leadership has been the so-called 'Vision 2030' plan, unveiled in April last year by Deputy Crown Prince Muhammad bin Salman. Based on a report by consultants McKinsey, it aims to boost the country's private sector and slim down the public sector and bureaucracy, raising the private sector share of the economy from its current 40% to 65%. To assist this there will also be a huge $2-3 trillion Norway-style sovereign wealth fund which will be kick-started by the sale of an initial 5% stake in state oil company and virtual arm of government Saudi Aramco.

Key to the success of the initial phase of the plan will be expansion of Saudi Arabia's mining sector. This has already begun with gold and phosphates, and now will also encompass copper, zinc and aluminium. Other sectors targeted for investment are: petrochemicals, manufacturing, retail, tourism and hospitality, healthcare, finance and construction. The plan envisages an eye-watering $2 trillion investment programme intended to double Saudi Arabia's GDP over 14 years, and there are also targets in areas like renewable energy. However, there are serious questions about even Saudi Arabia's ability to raise such vast sums of cash, without a huge hike in oil prices or selling far more of Aramco than currently envisaged.

Another difficulty is that mining and petrochemicals do not create large numbers of jobs, and often require skills not possessed by the Saudi workforce, and this goes for other sectors too. While tourism, especially religious tourism, has potential for expansion, the reluctance of the Saudi government to issue visas has historically been the main factor preventing expansion.

In the meantime, the aim is to raise the government's non-oil revenues from $45 billion in 2015 to $266 billion by 2030, or about one third of projected income. Part of this may be achieved by a 5% sales tax to be introduced in 2019, but Saudi Arabia has so far resisted any form of income tax on its cosseted citizens. Even now, there is only a proposal for taxing incomes of non-Saudis, something which could away expatriates who mainly see the country as a tax-free place to stay for a few years and build up capital. There are also new taxes on tobacco, carbonated drinks, air tickets and travellers' arrivals and departures.

## Ma'aden

Nevertheless, while elements of the Vision 2030 plan may prove to ultimately be too ambitious, the government's initial push into the mining sector has certainly been an eye-catching one, especially in the phosphate sector. Saudi Arabia is a large country – the 13th largest in the world – and has many deposits of strategic minerals. In order to exploit these the Saudi Arabian Mining Company ('Ma'aden') was formed as a joint stock company in 1997. It remains 50% government owned. Its initial foray was into gold and base metals, but it now has three other business areas, covering aluminium, industrial minerals (bauxite, kaolin and magnesite) and phosphates.

Middle East phosphate deposits are concentrated in a broad swathe of territory stretching from Egypt, through Israel and Jordan, southern Syria, western Iraq and northwestern Saudi Arabia, and the Saudi deposits form what is referred to within Saudi Arabia as the Northern Phosphate Region. It is reckoned that the country has up to 7 billion tonnes of phosphate rock in this region, with a $P_2O_5$ content ranging from 16-32% and averaging around 20%. This is fairly evenly divided between two main licensing areas; Umm Wu'al, where there are inferred resources of 3.6 billion tonnes, and Al Jalamid, where there are inferred resources of 4.1 billion tonnes of phosphate rock.

**"Key to the success of the initial phase of the plan will be expansion of Saudi Arabia's mining sector.**

Saudi Arabia's phosphate sector is currently in the hands of two subsidiaries. The first is the Ma'aden Phosphate Company (MPC), which is a $5.5 billion 70-30 joint venture between Ma'aden and Sabic – the Saudi Basic Industries Co, itself a 70% state-owned company which produces fertilizers and chemicals. MPC is developing the Al Jalamid deposit, The other is the Ma'aden Wa'ad al-Shamal Phosphate Company (MWSPC), which is developing the Umm Wu'al deposit.

## MPC

The Ma'aden Phosphate Company was the first development. The $5.5 billion project comprises to main sites – the phosphate mine itself at Al Jalamid, and a production site at Ras al Khair on the Red Sea coast, 90 km north of the fertilizer complex Al Jubail. At Al Jalamid 11.6 million t/a of phosphate ore is dug out and then beneficiated to become 5.0 million t/a of concentrate at a $P_2O_5$ content of 32-33% via a flotation method. This concentrate is then shipped via the 1,500 km North-South rail line – construction of which allowed the conception of the project – to Ras Al Khair, where the main production facility is based. Ras Al Khair houses the integrated fertilizer and chemical facility, comprising phosphoric acid and sulphuric acid capacity, a 1.1 million t/a Topsoe ammonia plant, DAP production and granulation, as well as utilities including a co-generation and desalination plant and other infrastructure. The site produces approximately 3.0 million t/a of granular diammonium phosphate from 700,000 tonnes of ammonia and 1.5 million t/a of phosphoric acid, plus a surplus of approximately 400,000 t/a of excess ammonia. Sulphuric acid capacity at the site is 4.5 million t/a in three huge sulphur burning plants designed and built by Outotec. Construction work was completed in 2010, with progressive ramp-up of phosphate production during 2011 and commercial DAP output beginning in February 2012.

## MWSPC

As the MPC project was starting up, Ma'aden announced its second phosphate project, based on the Umm Wu'al deposit. This project, at $7.5 billion, was even larger than the first and, while Ma'aden and Sabic were again co-developers, a foreign partner was involved this time in the form of US phosphate producer Mosaic. In what is its first major venture outside North America, Mosaic has taken a 25% stake in the project, with Ma'aden holding a majority 60% share, and Sabic the remaining 15%. Mosaic is taking 25% of the output – around 750,000 t/a of phosphate – as part of its participation.

The phosphate deposit at Umm Wu'al is about 17-21% $P_2O_5$, and averages about 20.3%, and it has low levels of magnesium oxide and incorporated heavy metals. The low levels of impurities led to it being earmarked for industrial and feed phosphate production rather than fertilizer, allowing Ma'aden to extend its portfolio into all areas of phosphate production. Production is based on three sites, from the mines at Umm Wu'al at the newly developed Wa'ad Al-Shamal Industrial City in the northern Tareef province, and additional facilities at Ras al Khair. Total mine output is 16 million t/a of phosphate rock, with concentration to 32% $P_2O_5$ and onward transport to the Wa'ad Al Shamal Mining City. Here production includes 100,000 t/a of food grade phosphoric acid, 90,000 t/a of industrial grade sodium polyphosphate, 250,000 t/a of animal feed grade dicalcium phosphate and monocalcium phosphate, and 280,000 t/a of phosphate and compound fertilizers, with a 1.5 million t/a (in terms of $P_2O_5$) phosphoric acid complex. However, some of the phosphate concentrate is also taken by rail to Ras Al-Khair, where there is now additional DAP production via a second ammonia plant. Projected sulphur consumption at Wa'ad al Shamal is 1.7 million t/a at capacity, feeding three 5,000 t/d MECS-designed sulphuric acid plants. Construction was completed at the end of 2016, and phosphate production is expected to ramp up throughout 2017.

## A third project?

With MWSPC now in start-up, Ma'aden has moved on to considering a third mega phosphate project. Few details are as yet available, but in December Ma'aden said that it is now looking at an additional 3 million t/a of phosphate output by 2024, at a projected cost of $6.4 billion, and that the project is still subject to completion of feasibility studies and consents. The project would take Ma'aden's phosphate output to 9 million t/a.

Other mooted projects on the phosphate side include an expansion of potassium sulphate (SoP) production at the Al-Biariq Fertilizer Plant Co. Ltd, sited on the Red Sea. German potash producer K+S has recently taken a 30% stake in Al-Biariq, and says that it plans to double SoP production form the present 20,000 t/a to 40,000 t/a.

## Sour gas

In addition to expansions in the mining sector, Saudi Arabia is looking to diversify its power sector. Saudi Arabia has traditionally burnt oil to produce power, but as its requirements for power generation have expanded, has found itself losing 900,000 bbl/d of oil in this way. While there are ambitious targets for new wind and solar power generation as part of Vision 2030, amounting to 4% of power production by 2020 and 10% by 2030, one of the major ways that Saudi Arabia is trying to wean itself off oil-based power generation is via the use of natural gas. Unfortunately, most of the country's natural gas reserves (ca 70%) are associated with oil fields, and often used to be flared. Over the decades there has gradually been a programme of collecting this via the Master Gas Gathering System. Nevertheless, producing gas only from oil fields limits gas production according to OPEC oil quotas. Thus as Saudi Arabia tries to move to generating 70% of its power from natural gas (up from the present 50%), it has had to turn to non-associated gas fields, virtually all of which are highly sour. A major programme of sour gas development is now under way, seeing gas output from both onshore and offshore sour gas fields and brought to a string of major gas processing plants.

## Karan

Karan was the first of Saudi Arabia's non-associated sour gas developments, with the $5 billion project beginning production in 2012. The gas from the offshore Karan field is brought ashore via a 100

Fig 1: **Saudi Arabia's sulphur producing and consuming facilities**






1 47 2 48 3 49 4 50 5 51 6 52 7 53 8 54 9 55 10 56 11 57 12 58 13 59 14 60 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46

km pipeline to be processed onshore at the existing Kursaniyah gas plant. Kursaniyah was expanded to handle the extra gas from Karan, with three additional processing trains each capable of handling 600 million scf/day. Hydrogen sulphide content in the Karan gas is about 2%, and sulphur production from the processing plant runs at about 900 t/d (300,000 t/a).

## Wasit

Sited north of Jubail Industrial City, the $5 billion Wasit gas plant was built to process gas from the offshore Arabiyah and Hasbah sour non-associated gas fields. Total gas processing capacity at Wasit is 2.5 billion scf/d to produce 1.7 billion scf/d of sales gas. Here the $H_2S$ content averages 4-8%, and the sulphur recovery section includes four SRUs with a total capacity of 4,800 t/d (1.6 million t/a). Liquid sulphur is pumped to Jubail. Commissioning began in February 2016 and has progressed throughout the year.

## Fadhili

The third gas processing plant is Fadhili, designed to process additional gas from the Kursaniyah and Hasbah sour gas fields. Target production has been increased to 2.5 billion scf/d, including 2.0 billion scf/d from Hasbah and 500 million scf/d from Kursaniyah. Contracts for the $13 billion project were awarded in July 2016 to Larsen & Tubro for offshore facilities, Saudi KAD for downstream, Saudi Electric and Engie for the combined heat and power (CHP) plant, and Mohammed I. Al Subeae & Sons Investment for the residential camp. Fadhili is scheduled to be completed by the end of 2019. Sulphur production at capacity is expected to be 4,000 t/d (1.3 million t/a).

## Kidan

As well as offshore sour gas fields, there are also moves afoot to develop onshore gas in the so-called Rub al-Khali (‘Empty Quarter’) of the Saudi desert. Prime among these was the Kidan gas field, where Aramco was to be partnered by Royal Dutch Shell. However, Shell quit the $4 billion project in 2014, concerned about the cost of the development in such a remote and forbidding area, and at the low price paid within Saudi Arabia for sales gas – fixed at just $0.75/MMBtu – and making the sulphur output from the plant a key component of the economics. Shell’s pull-out from Kidan followed other disappointments in the Rub al-Khali in which international joint ventures either failed to find gas or discovered deposits that were deemed uneconomic to exploit, and the future of the project remains in doubt.

## Midyan

Finally, there is also a 75 million scf/d gas processing plant at Midyan which is nearing completion, but this will process sweet gas and will not have a significant sulphur output.

## Refineries

While Saudi Arabia has long been the world’s largest oil exporter, another component of the Vision 2030 strategy is to develop more downstream petrochemical capacity, and part of this involves greater processing of crude domestically for export of finished products. While Saudi Aramco has equity stakes in various refineries worldwide, its wholly-owned domestic refineries have a capacity of only around 1 million bbl/d, including the Riyadh refinery (120,000 bbl/d), Jeddah refinery (100,000 bbl/d), Yanbu refinery (225,000 bbl/d) and Ras Tanura refinery (550,000 bbl/d). However, the company also has varying stakes in domestic joint ventures like PetroRabigh with Sumitomo Chemicals 400,000 bbl/d), Samref with ExxonMobil at Yanbu (400,000 bbl/d), Yasref with China Petroleum & Chemical (SNP) (400,000 bbl/d, also at Yanbu), Sasref with Shell (305,000 bbl/d), and Satorp with Total (400,000 bbl/d), both at al Jubail, all of which add another 1.9 million bbl/d of capacity. Saudi Aramco is also in the process of constructing a wholly-owned refinery, the Jazan Refinery, with a capacity of 400,000 bbl/d, which will be completed by 2018. Sulphur output at Jazan is expected to be 400,000 t/a, and another 100,000 t/a will come from an expansion at Rabigh.

## Sulphur balance

Saudi Arabia’s new focus on mining, petrochemicals and sour gas is leading to large volumes of additional sulphur consumption on the phosphate side, and additional sulphur production on the sour gas and refining side. Saudi Aramco reported sulphur production of 4.4 million t/a in 2014 and 4.9 million t/a in 2015, but as of the end of 2016, it is estimated that it has a sulphur production capacity of 4.5 million t/a from its gas processing projects and 1.0 million t/a from refineries, for a total of 5.5 million t/a. By 2020 these figures are estimated to increase to 5.8 million t/a from gas processing and 1.5 million t/a from refining, or a total of 7.3 million t/a. Set against this, sulphur consumption in Saudi Arabia is relatively small, and the additional demand represented by Ma’aden’s phosphate plants has been seen as a positive, as it absorbs some of the large sulphur surplus. Sulphur demand at Ras Al-Khair is currently about 1.3 million t/a, and it is anticipated that the new Umm Wu’al project will more than double that demand to 3 million t/a.

Saudi Aramco exported 3.6 million t/a of sulphur in 2014 and 3.8 million t/a in 2015. This figure fell in 2016 to about 3.4 million t/a, but is expected to rise past 4 million t/a this year, and should stay at or above that level in spite of the new phosphate capacity as new sour gas and refining capacity comes on-stream over the next few years.

# Sulphur World Symposium 2017

The Sulphur Institute (TSI)'s Sulphur World Symposium 2017 will be held from April 23rd-25th 2017 in Dublin, Ireland.

The Sulphur Institute is proud to host the Sulphur World Symposium 2017, an annual event that attracts sulphur industry leaders for two days of expert speakers, networking events, and industry tours. Over 150 delegates from over 30 countries are expected at this year's event. Whether it is a review of leading industry practices or an analysis of the sulphur supply and demand forecast, TSI's speakers incorporate information on the entire industry value chain.

PHOTO: DORAM / ISTOCKPHOTO.COM

*The Ha'penny Bridge, Dublin.*

**For further information see:**
**www.SulphurInstitute.org/Symposium17**

## Main session presentations

### Global sulphur and sulphuric acid outlook

**Fiona Boyd and Freda Gordon, Acuity Commodities**

Acuity's presentation will analyse changes in sulphur supply and demand and their subsequent impact on the market, including trade flows. Examples of supply changes include Kashagan in Kazakhstan beginning to produce in 2017 after years of delays. We will also focus on changes in infrastructure such as new forming capacity coming online in Canada this year. Trends to watch will also be reviewed, including a shift in the European market resulting in potential solid sulphur melter and forming projects.

For sulphuric acid, similar topics will be explored including the impact of increased sulphur-based production on the traded smelter acid market. On the infrastructure side, changes such as new import tank capacity will be reviewed. Changes in global acid supply and demand will also be covered as well as the outlook for key import regions such as Morocco and the US. It will also focus on regional trends such as supply from smelters in Japan/South Korea staying closer to home in the southeast Asian region reducing exposure to further long haul markets such as Chile. The import deficit in Latin America will also be examined including expected higher requirements for markets such as Argentina and Mexico.

### The new phosphates paradigm – integration, consolidation and regionalisation – changing patterns in global phosphates sales and trade

**Mike Nash, Argus Media Ltd**

In this presentation, Argus Phosphates editor Mike Nash gives his view on changes in the global phosphates market, the new sales strategies adopted by the supply side and drivers of recent changes in trade patterns. From vertical integration along the supply chain as producers seek to garner market share in key markets, the changing role of traders within the industry to greater consolidation on the supply side and the rise of China as a dominant phosphates exporter, as well as increased regionalisation in trade and the redrawing of the global phosphates map, Mike takes us through the key trends, the fundamental reasons behind them and what it means for the future.

### Sour gas project update

**Richard Hands, Editor, Sulphur Magazine, BCInsight Ltd**

A review of the progress of a number of sour gas projects across the Middle East, Central Asia and China, which are collectively delivering a large boost in sulphur production; a boost which has pushed the market into surplus. But in a world of cheap oil and gas, are the additional costs that sour gas projects face still justifiable? Is this likely to be a one-time addition, or will it lead to a more sustained growth in sulphur output?

### Prospects for sulphur transportation costs: is the dry bulk freight market about to pounce?

**Marc Pauchet, Maersk Broker K/S**

This presentation will provide a look at where sulphur lies in the global dry bulk freight market and the demand outlook. A profile for dry bulk vessel supply will be given with an emphasis on smaller ships. New regulations impacting the industry scheduled for implementation will be highlighted.

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The Turkmenchimia sulphuric acid plant, Turkmenistan.

# Sulphuric acid project listing 2017

*Sulphur*'s annual survey of recent and planned construction projects in the sulphuric acid industry includes several large-scale acid plants both for phosphate processing and to capture sulphur dioxide from smelters.

| Company | Site | Application | Capacity | Licensor | Contractor | Type of project | Start-up date |
|---|---|---|---|---|---|---|---|
| **AUSTRALIA** | | | | | | | |
| Nyrstar | Port Pirie | Smelter off-gas | n.a. | Outotec | Outotec | Revamp | 2017 |
| **BRAZIL** | | | | | | | |
| Nitro Quimica | Sao Paolo | Sulphur burning | 900 t/d | Chemetics | Chemetics | Revamp | 2018 |
| Paranapanema | Camacari | Smelter off-gas | 3,144 t/d | Chemetics | Chemetics | Revamp | 2016 |
| **CANADA** | | | | | | | |
| Glencore | n.a. | Smelter off-gas | n.a. | Chemetics | Chemetics | Revamp | 2018 |
| Teck Resources | Trail | Smelter off-gas | 1,030 t/d | Chemetics | Chemetics | New | 2019 |
| Vale | Sudbury | Smelter off-gas | n.a. | Chemetics | Chemetics | Revamp | 2017 |
| **CHILE** | | | | | | | |
| Codelco | Potrerillos | Smelter off-gas | n.a. | Outotec | Outotec | Revamp | 2018 |
| Codelco | Chuquicamata | Smelter off-gas | 2 x 2,050 t/d | MECS | SNC Lavalin | New | 2019 |
| **CUBA** | | | | | | | |
| Moa Joint Venture | Moa Bay | Sulphur burning | 2,000 t/d | Chemetics | n.a. | New | 2016 |
| **DEMOCRATIC REPUBLIC OF CONGO** | | | | | | | |
| Tenke Fungurume Mining | Tenke Fungurume | Sulphur burning | 1,400 t/d | Chemetics | Chemetics | New | 2016 |
| **FINLAND** | | | | | | | |
| Boliden | Harjavalta | Smelter off-gas | n.a. | Outotec | n.a. | New | 2019 |
| Metsa Group | Aanekoski | Paper mill off-gas | 35 t/d | n.a. | Valmet | New | 2017 |

| Company | Site | Application | Capacity | Licensor | Contractor | Type of project | Start-up date |
|---|---|---|---|---|---|---|---|
| **EGYPT** | | | | | | | |
| El Nasr | Ain Sukhna | Sulphur burning | 2 x 1,900 t/d | Outotec | Intecsa | New | 2018 |
| **INDIA** | | | | | | | |
| Aarti Chemicals | Vapi | Sulphur burning | 230 t/d | Chemetics | Chemetics | New | 2017 |
| Paradeep Phosphates | Paradeep | Sulphur burning | 2,000 t/d | MECS | Chemetics | New | 2016 |
| **IRAN** | | | | | | | |
| NICICO | Sarcheshmesh | Smelter off-gas | n.a. | Outotec | n.a. | New | 2018 |
| **MOROCCO** | | | | | | | |
| OCP | Jorf Lasfar | Sulphur burning | 4,200 t/d | MECS | n.a. | New | 2017 |
| **NAMIBIA** | | | | | | | |
| Namibia Custom Smelter | Tsumeb | Smelter off-gas | 1,000 t/d | Outotec | Outotec | New | 2016 |
| **NETHERLANDS** | | | | | | | |
| Nyrstar | Budel | Smelter off-gas | n.a. | Chemetics | Chemetics | Revamp | 2017 |
| **NEW ZEALAND** | | | | | | | |
| Balance | n.a. | Sulphur burning | 625 t/d | Chemetics | Chemetics | Revamp | 2017 |
| **PERU** | | | | | | | |
| SPCC | n.a. | Smelter off-gas | n.a. | Chemetics | Chemetics | Revamp | 2016 |
| SCC | Tia Maria | Smelter off-gas | 1,640 t/d | Outotec | n.a. | New | 2017 |
| Votorantim | Cajamarquilla | Smelter off-gas | n.a. | Outotec | Outotec | New | 2016 |
| **RUSSIA** | | | | | | | |
| Ural Mining | Svyatogot | Smelter off-gas | n.a. | Outotec | Outotec | Revamp | 2018 |
| **SAUDI ARABIA** | | | | | | | |
| Ma'aden | Umm Wu'al | Sulphur burning | 3 x 5,050 t/d | MECS | SNC Lavalin | New | 2017 |
| **TUNISIA** | | | | | | | |
| Groupe Chimique Tunisien | Gafsa | Sulphur burning | 1,800 t/d | MECS | n.a. | New | 2017 |
| **TURKEY** | | | | | | | |
| Cengiz Group | Samsun | Smelter off-gas | n.a. | Outotec | n.a. | Expansion | 2016 |
| **TURKMENISTAN** | | | | | | | |
| Turkmenchimia | n.a. | Sulphur burning | 1,500 t/d | MECS | n.a. | New | 2016 |
| **UGANDA** | | | | | | | |
| Sukuru Phosphate | Tororo | Sulphur burning | 600 t/d | n.a. | n.a. | New | 2016 |
| **UNITED STATES** | | | | | | | |
| Mississippi Power | Kemper, MS | Gasification | 400 t/d | n.a. | n.a. | New | 2016 |
| Freeport McMoRan | Miami, AZ | Smelter off-gas | n.a. | n.a. | n.a. | On hold | 2017 |
| **UZBEKISTAN** | | | | | | | |
| Ammophos-Maxam | Almalyk | Smelter off-gas | 2,000 t/d | n.a. | n.a. | New | 2018 |
| Navoi Mining | Uchkuduk | Sulphur burning | 2,000 t/d | n.a. | n.a. | New | 2019 |
| **ZAMBIA** | | | | | | | |
| Kansanshi Mining | Solwezi | Smelter off-gas | 4,400 t/d | Outotec | Outotec | New | 2016 |

# Automated remelt program for sulphur pipelines

Pentair Thermal Management has recently introduced AUTO-Melt™, a unique approach for a safe and reliable automated remelt program for sulphur pipelines that does not require continuous operator assistance. This article provides the basic pipeline design requirements necessary to collect data that will allow an automated remelt program to be developed, and discusses the creation of a data-driven software platform which allows for fact-based decision making by pipeline operators when managing the pipeline in various flow regimes.

PHOTO: PENTAIR THERMAL MANAGEMENT

*Engineered "thermally isolated" sliding pipe support and pipe anchor.*

The most critical issue in the performance and operational life of a sulphur pipeline is the safe and reliable remelt of solidified sulphur to re-establish flow. While most attention has historically been placed on assuring that the required pipeline maintenance temperature is achieved during normal operations, a failure to address the safe, reliable and repeatable remelting of the solidified sulphur in the pipeline could result in a plant shutdown due to a pipeline rupture or damage from excessive movement and/or pipe anchor failures. In the worst case scenario, the rupture could cause a serious event such as hot liquid sulphur being discharged from the pipeline – resulting in damage to the environment and even the possible loss of life. The current best practice is to employ skilled operators (who may or may not be specially trained) to manage the remelt program.

Until now, the ability to implement an automatic remelt program for sulphur pipelines has served as an idyllic vision rather than reality. This article presents a new and unique approach for a safe and reliable automated remelt program without the requirement for continuous operator assistance, through the utilisation of compelling pipeline operating data extracted from the commissioning, start up and initial remelt activities to automate the heat-up of solidified sulphur in the pipeline. State-of-the-art technologies such as continuous fibre optic distributed temperature sensing can be combined with other advanced pipeline instrumentation methodologies to gather key decision-making data. With recent developments in predictive modelling, transient analysis and improved software solutions, it is now possible to create a dynamic, real-time model for the solidified sulphur as it transforms through its phase change inside the pipeline. As the potential exists for remelting to occur at different rates in various portions of the line, it is imperative to perform this activity in a manner that does not allow for overpressure or other pipeline failure modes to occur.

State-of-the-art technologies such as continuous fibre optic distributed temperature sensing can be combined with other advanced pipeline instrumentation methodologies to provide key inputs for customised algorithms to drive logic-based decisions.

The ideal goal of achieving a "100% uniform thermal profile" along the entire constructed sulphur pipeline alignment is often unrealistic; localised thermal discontinuities (from a heat transfer perspective) can create a complex and dynamic environment along a sulphur pipeline. These discontinuities could include pipeline void spaces (liquid free zones), excessive heat loss zones (such as pipe supports/anchors) and the impact of elevational changes (peaks/valleys and/or vertical risers). Experience has shown that expansion loops and anchor locations can be critical monitoring locations during a remelt activity. Thus, a dense mesh, accurate mapping of the rate of temperature change, along with other operational parameters, can yield a much more sophisticated and predictable real-time model for sulphur remelt. The development of specialised algorithms based on trends in measured data during commissioning and preliminary start-up could provide the early indication of potential failure modes and can serve to more precisely monitor and assess dynamic pipeline conditions, attributing to the successful implementation of a customised automated sulphur remelt program.

## Critical design and operational issues

When planning a new sulphur pipeline, there are key aspects to consider early in the project cycle, which will ultimately determine the operational benefits of the completed asset. The physical properties of sulphur and its narrow operating temperature zone create many design challenges. Since sulphur will begin to freeze at temperatures around 119°C, most pipelines are operated at a temperature between 135°C and 150°C.

There is a symbiotic relationship between three design criteria categories that must be understood and carefully considered:

- **Pipeline mechanical design:** configuration issues, supports, anchors and expansion loops and pipe movements
- **Sulphur material properties:** physical characteristics that drive design considerations
- **Pipeline heating system:** its design, and the integration of other applicable technologies that can collect valuable data for an automated sulphur remelting program

## The sulphur pipeline challenge

To construct a world class liquid sulphur pipeline requires the early understanding of the key design criteria drivers. Then, it becomes imperative to incorporate these ideas and philosophies into the project requirements at an early stage – usually, this is the pre-FEED study for a large pipeline project. Key issues must be proactively addressed at the early stage; otherwise, it may be too late to incorporate certain features, leaving the asset owner to ultimately deal with the result of poor planning. Some of the key design considerations are addressed in this article.

## Flow regimes

It is important to recognise that every liquid sulphur pipeline will almost certainly experience three different flow regimes during its operational life:

- Flowing: moving molten sulphur, (temperature above freezing).
- Stagnant: liquid sulphur not flowing, but still in a molten state, (requiring flow to resume).
- Plugged: portions of pipeline have experienced sulphur solidification, (with formation of voids).

Each flow regime must be handled in a very different way by pipeline operators with pre-planned appropriate data collected from the pre-commissioning testing activity onwards. The third regime (a plugged pipeline) is the most critical and troublesome issue for sulphur pipeline operators when trying to re-establish flow.

## Common failure modes for liquid sulphur pipelines

Those who have experienced a pipeline rupture will readily admit that the subsequent forensic root cause analysis is a complex and arduous task. It requires a deep understanding of the many intricacies and complexities of the asset, a pipeline's design basis, construction records, and circumstances leading up to a rupture event. Generally, for sulphur pipelines it is the solid-to-liquid phase change (and the accompanying expansive forces from the volume increase) that creates problems for operators, sometimes leading to a catastrophic pipeline failure.

History has shown that some of the most common sulphur pipeline failures are caused by:

- pressure build-up in the pipeline due to a lack of pressure management;
- welded pipe shoes or faulty anchor design, with high heat loss (often up to 75% extra heat loss);
- insufficient thickness and/or poor field installation of thermal insulation;
- inability to monitor the pipeline temperature along the entire length of the pipeline;
- absence of any extra heat delivery capability during "emergency conditions" when localised heat losses create cold zones along the pipeline;
- excessive pipeline movements;
- "runaway heating" (overheating) at voids/empty zones, present in the pipeline from either elevation or sulphur solidification;
- absence of a clear and methodical sulphur remelt procedure.

## Heat loss management and a uniform thermal profile

When heating a pipeline for any service, but particularly so for very high operating temperatures, it is imperative to maximise the efficiency of the thermal envelope around the pipeline. Embedded in this discussion is the idea of creating a "uniform thermal profile", where, ideally, no heat sinks occur along the pipeline that would cause excessive amounts of heat to be lost in localised areas. For example, this situation can occur when components such as pipe supports and anchors are designed solely to minimise the pipe movements, without regard to thermal heat loss preservation. In addition, poorly installed thermal insulation itself can jeopardise the pipeline heat loss uniformity.

A uniform thermal profile is critical, because without it pipeline management becomes difficult, or even impossible! This key aspect is addressed later in the next section with the concept of an Intelligent Sulphur Pipeline.

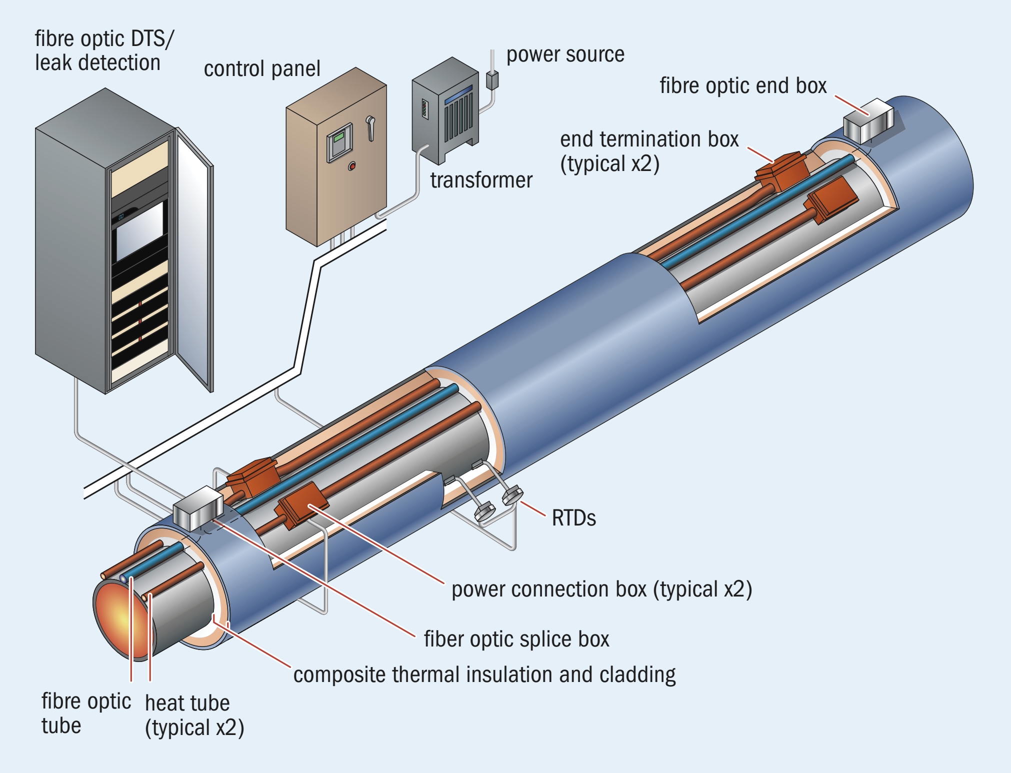
## Intelligent sulphur pipeline features

The introduction of "intelligent pipelines" with state-of-the-art bundled technologies in recent years has been a dramatic and significant milestone in the heated pipelines of liquid sulphur, especially for long pipeline applications. It is a unique technology integration concept that has proven to be a winning formula in making many sulphur pipelines more reliable and more predictable to operate.

Technology bundling for sulphur pipelines incorporates a "fit-for-purpose" integration of an applicable state-of-the-art "skin-effect" electrical pipeline heating technology (STS), with the use of pre-insulated piping (PIP) to achieve a homogenous thermal profile for the entire pipeline, a fibre optic based sensing system such as distributed temperature sensing (DTS) to monitor pipeline temperature, and engineered pipe supports and anchors that minimise localised heat loss. Further, the latest concepts in computational modelling and transient analysis can provide the safest and most efficient remelt procedure available in the industry today.

Together, all of these system components and customised procedures create

Fig 1: **Skin-effect heating system (with fibre optic DTS) on a sulphur pipeline**




tremendous synergies in the operation of sulphur transport pipelines.

The following section provides a short description of the primary key strategic components incorporated in developing an intelligent liquid sulphur pipeline. The adoption of this breakthrough innovation in sulphur transportation has added valuable experience and confidence enabling the user to strive for a 100% safe sulphur remelt capability for all future sulphur pipelines. The intelligent sulphur pipeline approach incorporates five key strategic components:

- skin-effect heat management system;
- pre-insulated pipe;
- fibre-optic technology;
- thermally insulated pipe supports and anchors;
- safe and reliable remelt procedure.

**Skin-effect heat management system:** a proven and widely accepted electrical trace heating technology with over 50 years of installed base (Fig. 1).

**Pre-insulated pipe:** utilising today's best available technology provides predictable heat loss and offers a homogenous thermal profile for the pipeline (Fig. 2).

The bundling of pre-insulated pipe with skin-effect heating is a natural fit. Some major advantages of utilising a pre-insulated piping system include:

- Higher quality; factory tested and inspected
- Construction schedule improvements; ease and quickness of installation
- Lower installed cost vs field insulated and fabricated piping systems
- Durable construction
- Reduced maintenance

**Fibre optic technology:** the ability to gather real-time thermal intelligence data can be highly valued by pipeline operators, enhancing the safety and reliability of the pipeline.

Various fibre optic technologies exist for pipeline monitoring, including distributed acoustic sensing (DAS), distributed vibrational sensing (DVS) and distributed temperature sensing (DTS). For most distributed sensing techniques, a pulsed laser is coupled to an optical fibre through a directional coupler (Fig. 3). Light is backscattered as the pulse propagates through the fibre's core owing to changes in density and composition as well as molecular and bulk vibrations. In a homogeneous fibre, the intensity of the sampled backscattered light decays exponentially with time. Because the velocity of light propagation in the optical fibre is well known, the distance can be calculated from the deterministic collection time of the backscattered light. Thus, the measured parameter and distance can be identified simultaneously.

Fig 2: **Pre-insulated piping sections**

A major component of the fibre optic based measurement system is the interrogation electronics. This is comprised of a light source (high intensity laser) and a specialised OTDR (optical time domain reflectometer) with software to analyse specific spectral signals for distributed or point measurement information.

In the case of DTS, this system provides "thermal intelligence" by monitoring the temperature along the entire pipeline, giving operators a clear and visual understanding of the thermal profile of the pipeline and how the heating system is operating.

With DTS, a temperature profile is generated along the entire pipeline, greatly assisting in daily decision-making to operate the pipeline efficiently and safely. The inclusion of fibre optic DTS also offers accurate historical records by recording sulphur temperatures during routine operations and excursion events. DTS is particularly important during the remelt process of solidified sulphur.

**Thermally isolated pipe supports and anchors:** critical for uniform heat loss along the installed sulphur pipeline, eliminating localised "heat sinks" which can result in pipeline failure. It is important to eliminate metal-to-metal contact.

**Safe and reliable remelt procedure:** proven methodology, with the flexibility to handle all types of terrain on which the pipeline is installed and supported with real world experience.

## AUTO-Melt™ for sulphur pipelines

By introducing the "AUTO-Melt™" program, the sulphur remelting process becomes much more predictable, with less left to "chance". AUTO-Melt™ is a new and automated remelt program, based on pipeline and other dynamic data and information gathered from the intelligent pipeline approach for liquid Sulphur pipelines.

Some of the important features and components are discussed in the following sections. These components include custom algorithms and a customised

1 47 2 48 3 49 4 50 5 51 6 52 7 53 8 54 9 55 10 56 11 57 12 58 13 59 14 60 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46



pipeline management console based on core logic modules. The AUTO-Melt™ program identifies and collects relevant dynamic data and relies on powerful customised software to create a remelt program that is timely, automated and fail-proof.

## Predictive pipeline behaviour using custom algorithms

Historically, the management of liquid sulphur pipelines has been left largely to the shift operator who uses his judgement and experience to make appropriate decisions. This is a highly manual and operator dependent approach, with limited or no real-time data used to drive decisions. It becomes, many times, a "best guess" approach to managing the pipeline that will lead to poor pipeline behaviour, and possibly pipe rupture.

It is possible to create a data driven, automated remelt/re-heat methodology for a liquid sulphur pipeline that combines data generated from various integrated technologies to feed custom algorithms. The result is a sophisticated proprietary software framework with asset mapping, parameter benchmarking, dense data collection and specialised data manipulation techniques, all delivered through a dedicated "custom dashboard" on a master data management display console.

## Master data console: A pipeline management tool

The new development of special algorithms created from data measured during testing (precommissioning), commissioning and pipeline start-up can be applied to a predictive pipeline behaviour model. This breakthrough has resulted in the creation of a new specialised software framework for the management of sulphur pipelines.

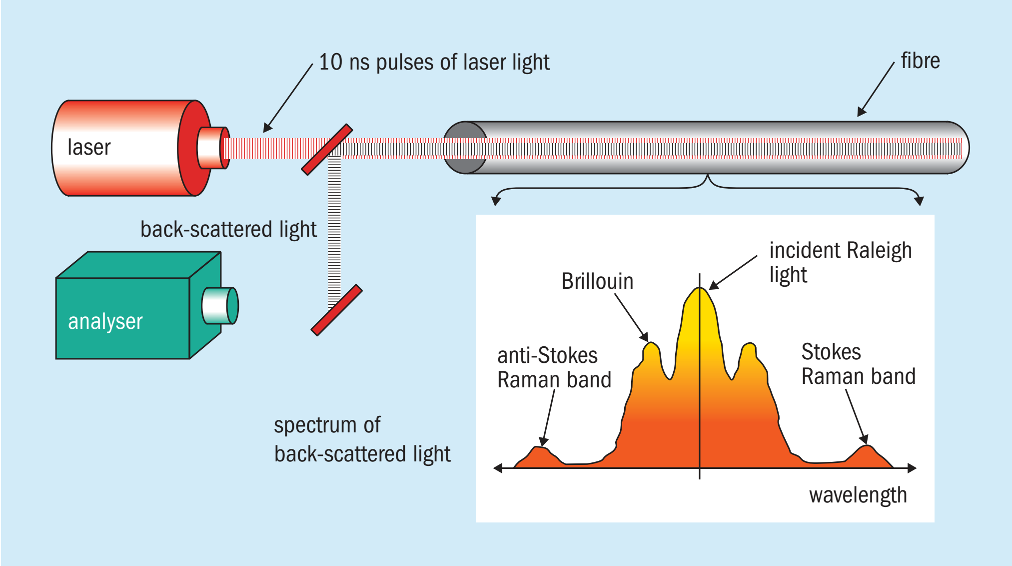
The data processing contained in the algorithms goes well beyond the classical pipeline temperature monitoring, which is often limited to providing pre-alarms or alarms when the pipeline temperature has moved out of the acceptable range for some portion of the pipeline.

## Core logic module for AUTO-Melt™ program

The pipeline management program's data collection and data analysis are contained in the system's many logic modules, which are used in the support of the day-to-day operation and maintenance of the pipeline.

The modules generally fall into one of three categories:

**Fig 3: DTS functionality**




- Operations
- Maintenance
- Special case

The AUTO-Melt™ pipeline manager is one of the special case processing modules included in this overall package.

## Building custom algorithms

The customised algorithms built into the software framework make use of a variety of sensor inputs. These inputs may include both distributed and discrete measurements.

## Customised "smart dashboard" to assist operator decision

Information generated by the operations, maintenance, and special case logic modules is organised and presented at the system console using a custom "smart dashboard" user interface. This interface allows control room personnel to immediately identify the current state of the pipeline and to initiate appropriate responses or actions recommended by the software. Using conventional navigation tools, users can toggle between a wide range of advanced data summary and analysis screens. The software sends automated messages, as required, to notify personnel of conditions on the pipeline that require attention or intervention.

## Case studies

The automated remelt case is engaged when the operations module algorithms detect and respond to a plug or frozen section in the pipeline. The following two historical case studies highlight scenarios that can be detected and remelted by the logic embedded in the pipeline management tool.

### Case study 1

In this case study a localised plug in the pipeline was preventing flow, despite the fact that the pump was operating.

In this example, the empty pipeline was pre-heated, filled for the first time, and then gravity drained. After a short period to drain the line, the pipeline's heating system was switched off, and the pipe was allowed to cool down to ambient conditions. Shortly afterward, the pipeline was again re-heated to its operating set point. During the subsequent re-introduction of liquid sulphur, flowmeter data showed that the flow had stopped completely, despite the fact that the pump was running and the pump outlet pressure was normal.

It became clear that the pipeline flow was obstructed by a localised plug in the line.

To determine the exact location and size of the localised solid sulphur plug, the logic modules analysed the spatial variance of the DTS data along the pipeline. This combination of inputs (pump running, pressure normal, flow stopped and DTS temperature variance showing bimodal behaviour) allows the logic modules to determine the presence and precise location of the plug.

In post-analysis of the data collected by the management system, it was determined that the sulphur did not fully drain from the pipeline, and that small sections of pipe near uninsulated drains were plugged by sulphur freezing during the drainage/cool down activity. This led to formation of the plugs and the blockage experienced during the liquid sulphur re-introduction.

In this plugged pipeline case, the system algorithms immediately assess the distribution of the solid sulphur phase in the pipeline. This is critical, as the type and extent of the remelt process to be utilised depends on the extent to which the sulphur has frozen.

The model showed the pipeline had localised plugging in four places. When the solid sulphur is localised within a few metres span of pipeline, it can be remelted by use of a partial remelt routine which temporarily maximises heater power in the affected area. In this case, the system will force on the heater zone which contains the frozen sulphur and identify the exact location of the plug for operations personnel so that the plug site can be visually inspected and externally heated if necessary. All unaffected zones will be set to cycle normally at their stagnant line set point. The system will return the heater zone to normal operation once thermal evidence has been collected by the system verifying that the plug remelt has been fully completed.

**Case study 2**

In this case, the entire pipeline was de-energised for an extended period of time resulting in the solidification of the sulphur throughout multiple heating zones.

When the algorithms detect that sulphur has solidified over longer sections of the pipeline, the system shifts into full remelt mode. A logic module determines the fill percentage data for the solid sulphur at one metre intervals along the entire pipeline. This provides the basic information needed to monitor the remelt.

The pipeline and drainage cool down module resolves the solid sulphur pipeline fill percentage into four categories:

- 76 to 100%
- 51 to 75%
- 26 to 50%
- 0 to 25%

This information is utilised during the remelt process to predict where the empty pipe volume is available to accommodate the sulphur expansion during its phase change back to the molten state.

## How "AUTO-Melt™" works

To begin the remelt process, the system utilises the various heater zones and power levels available to achieve a uniform pipeline temperature that is just below the sulphur melting point (in the pipeline sections that contain solid sulphur). If this is not achievable, the heating system will revert to the temperature maintenance mode and notify operations and maintenance staff of the existing non-uniformity issues, (specifically locating any problem areas to within ± 1 m). Any such issues must be resolved prior to the automated remelt being allowed to progress.

Once a uniform premelt temperature profile has been achieved, the pipeline management system will provide an operator prompt to verify that all pipeline valves, vents, and drains are properly set to the open position. This will provide the maximum available expansion volume to accommodate the sulphur phase change. Only after this prompt has been acknowledged by the operations staff will the system begin to increase the temperature of the pipeline toward the sulphur melting point.

As the temperature of the pipeline increases, the sulphur melt algorithm tracks the progress (on a metre-by-metre basis) of the sulphur phase change from solid to liquid. This data is analysed for uniformity at the critical pipeline sections (with low available expansion volume), as identified by the drainage and cool down algorithm. The pipeline management system controls the heater zones and available power levels to synchronise the phase change along these key pipeline sections. If, at any point in the automated remelt process, the algorithms are unable to achieve a spatially uniform phase change, the system will hold the pipeline temperature below the melting point of the sulphur and notify operations and maintenance personnel of the pipeline locations (by specific metre marks) where the required uniformity cannot be achieved. Only after control room personnel have verified that the uniformity problems identified by the system have been resolved, will the system re-start the automated remelt process engine.

When the system has verified that the remelt is complete, operations personnel will be instructed to close the pipeline's vents and drains and the heater setpoint will be increased to the stagnant liquid sulphur target value. Once the pipeline heaters are cycling normally at the stagnant liquid sulphur setpoint, the pumps can be started and the control software returned to its normal operating and maintenance mode.

## Conclusions

Heated liquid sulphur pipelines are at the threshold of achieving great milestones in design, operations, preventive maintenance, and the safe remelting of solidified sulphur in a pipeline. A new wave of technology allows sulphur pipeline operators to use "fact-based" logic in both routine and emergency decision-making for a variety of scenarios. With the help of pipeline operating data, new software and custom algorithms offer greater reliability and safety for the difficult sulphur remelt task. This concept will revolutionise the transportation of liquid sulphur in pipelines.

The main conclusions from this article can be summarised as follows:

- Pipelines are to be designed such that you minimise aspects that might create a non-uniform temperature profile.
- It is highly recommended that fibre optic temperature monitoring be incorporated into the pipeline design early in the project requirements phase.
- A predictive pipeline model can be constructed from customised asset data collected during the testing, start-up and commissioning phases of the project.
- It is possible to use algorithms and analytics to assist pipeline operators in the daily management of a sulphur pipeline, and during the critical task of remelting solidified sulphur.

## Acknowledgement

*This article is based on the Sulphur 2016 Conference paper "Automated re-melt program for sulphur pipelines – A revolutionary advancement in safety and state of the art bundled technologies by Franco Chakkalakal and Mike Allenspach of Pentair Thermal Management, Kent Kalar of Topside Solutions and Hasan Amarneh of GASCO.*

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# Maximising sulphuric acid plant profitability

Optimising plant profitability has always been an important aspect of operating any sulphuric acid plant. The current environment of low prices for sulphuric acid as well as the majority of products sold by acid producers, such as metals and commodity chemicals, makes optimisation of plant performance even more important to keep the business competitive. Acid producers can improve their competitive advantage in a variety of ways, including: reducing operational expenditures, increasing capacity and increasing on stream times.

With historically low prices on both sulphuric acid, commodity chemicals and metals, the pressure is high on acid plant operators to reduce costs and improve profitability. Reducing cost can be achieved in a number of different ways. In this article, we focus on plant upgrades, energy efficiency improvements, raising output and optimising the strategies for how the catalyst is chosen and operated.

## NORAM plant upgrades

To continue successful operation, all sulphuric acid plants will eventually need upgrades, even with good equipment designs. In some cases, plant owners may decide to buy a complete new plant, but this decision may not be realised due to the high costs, permitting challenges, and long lead times of a complete plant replacement. A plant modernisation project is typically a fraction of the cost of a complete plant replacement, and allows for better cash-flow and reduced amortisation of debt, as compared to a new plant project.

Drivers for plant upgrades may include:

- need to replace end-of life equipment;
- requirement to meet more stringent environmental regulations;
- new energy recovery targets, or
- need to increase gas handling or acid production capacities.

In addition, some acid plant components may need upgrading or replacement due to the age and mechanical condition of the equipment, or when they are found to be a bottleneck in the plant.

NORAM specialises in engineering strategies for upgrading plants. These modernisation strategies are best conceived as part of a long term plan. Upgrade factors include: process and mechanical engineering considerations, budgetary constraints, turnaround planning, duration of plant shutdown, lost production, technical risk, mechanical conditions of existing equipment, space availability, shipping restrictions, permitting, logistic considerations, as well as the time required for fabrication and installation of major equipment. NORAM also provides improved sulphuric acid plant technologies and equipment that can be utilised in plant upgrades.

### Replacement of equipment reaching end-of-life

In this case, certain pieces of equipment require replacement due to poor mechanical condition. In sulphuric acid plants, the issues are often caused by corrosion, or by design and installation issues. Sometimes, the life of major pieces of equipment can be extended by temporary repairs, but ultimately replacement is necessary. The following aspects can be considered to decide if a major piece of equipment should be replaced:

- probability of equipment failure;
- potential lost production;
- time required for engineering, fabrication and installation;
- total replacement cost.

A simple cost evaluation is often the best way to decide if equipment replacement is required. The plant personnel should calculate the potential costs associated with not replacing the equipment, and compare them with the costs of a complete replacement project.

The potential costs of not replacing the equipment (Amount A) should consider the following:

- potential lost production value per day of plant shut-down. This should be weighed by the estimated probability of failure over the lifetime of the equipment;
- time required for repairing or replacing the equipment in case of catastrophic failure. For large pieces of equipment, repairs or replacement may take many months to complete. Include time required to design, supply materials, shipping, fabrication and installation;
- cost of temporary repairs;
- increased maintenance costs;
- evaluate for a reasonable period of time (equipment lifetime).

The costs of replacing the equipment (Amount B) should consider the following:

- cost of basic engineering;
- cost of detailed engineering;
- equipment fabrication cost;
- shipping costs;

Table 1: **Equipment replacement considerations**

| Equipment type | Common reason for replacement | Life expectancy of old-style equipment | Technology improvements |
|---|---|---|---|
| Catalytic converters | ● Need to reduce $SO_2$ emissions.<br>● Gas leaks around nozzles and welds.<br>● Collapse of catalyst support plates or bed division plates.<br>● Inadequate conversion. Insufficient catalyst volume.<br>● Deformation and bulging of shell.<br>● Failure of support posts (if any).<br>● Failure of bed division plates.<br>● Corrosion from dewpoint control issues and inadequate pre-heating.<br>● Hot corrosion from operation under excessive catalyst temperatures (poor $SO_2$ concentration control).<br>● Thermal expansion issues.<br>● Other fouling and corrosion issues. | 20 to 40 years | ● All-welded designs.<br>● All-stainless steel designs (typically 304H)<br>● Catenary support plates.<br>● No requirement for support posts or internal core sections to use entire cross sectional area of converter. |
| Acid Towers | ● Bad stack ($SO_3$ and acid mist emissions).<br>● Inadequate $SO_3$ absorption.<br>● Shell corrosion and bulging.<br>● Damage of tower bottom.<br>● Acid leaks.<br>● Failure of brick-lining and spalling. | 20 to 30+ years | ● Improved process and mechanical designs.<br>● Improved bricking designs and dished bottom.<br>● Alloy towers. |
| Gas-to-gas heat exchangers | ● Failure of tube attachments to tubesheet.<br>● Damage to tubesheet.<br>● Corrosion due to acid condensation causing tube leaks.<br>● Fouling causing increased pressure drop.<br>● Thermal expansion issues.<br>● Inadequate heat transfer.<br>● Expansion joint failure. | 5 to 20+ years. Lower for cold exchangers made of carbon steel. Higher for hot exchangers made of stainless steel. | ● All-stainless steel designs (typically 304H).<br>● Low pressure drop designs.<br>● Designs with built-in metal temperature control to prevent condensation. |
| Acid Coolers | ● Acid leaks due to corrosion (concentration issues or impurities), high temperatures or erosion (too high velocities).<br>● Issues with anodic protection. | 5 to 30+ years | ● Alloy coolers |
| Piping | ● Acid leaks due to corrosion (concentration issues or impurities) or erosion (too high velocities).<br>● Cracking of gray cast iron piping causing extreme leaks.<br>● Flange leaks. | 5 to 20 years (lower for gray cast iron operating at high velocity). | ● Alloy piping.<br>● All-welded designs.<br>● Simplification of layout by using higher capacity pumps and coolers instead of units in parallel. |

*Source: NORAM*

- foundation costs (if required);
- erection and installation costs, considering plant turnaround planning.
- In general terms, if "Amount A" is larger than "Amount B", it is recommended to replace the equipment.

Table 1 shows some general indicators of equipment failure and provides approximate ranges for typical equipment life expectancy. Life expectancy of old-style equipment will strongly depend on the quality of the design and fabrication as well as the plant operation.

Other factors to consider include:

- service life of existing equipment;
- plant turnaround schedule;
- space constraints;
- other risks and safety considerations.

## New energy recovery targets

Many acid plants recover energy utilising a steam system (in particular sulphur-burning acid plants). A plant-wide simulation can be developed to identify opportunities for better energy integration and recovery. Findings can be materialised as reduced electrical power consumption, increased steam production or increased production of electricity.

Low pressure drop equipment can be installed to reduce the energy consumption by the plant blowers (for instance, lower electrical consumption by the main blower) and allows for increased capacity.

Examples of such equipment are:

- replacement of fouled equipment and catalyst;
- HP™ packing: having about half the pressure drop of conventional packing;
- radial flow gas-to-gas heat exchangers.

Many metallurgical or regen acid plants reject energy from process gas, by using $SO_3$ coolers that vent hot air to the environment. $SO_3$ coolers can be designed to remove process heat by indirect heat transfer to hot air. The hot air product can be used to feed combustion furnaces for increased energy production, or it can be used for indirect heat transfer to produce steam using steam equipment.

Energy can also be recovered from the cooling of sulphuric acid using a boiler feed water heater or a heat recovery system using a boiler on a staged hot acid absorption system.

## Increased gas handling and acid production

It is typically in the best interest of plant owners to increase production capacity. The reason for this is that the owner has an asset with fixed and variable operating costs. Increasing capacity is achieved with a relatively small increase in the variable cost, while profits are proportionally increased.

Reasons to consider increasing capacity for metallurgical plants include:

- new smelting equipment may have been acquired, or changes may have been made to the smelting equipment, that allow for further processing of minerals;
- air leakage may have increased the gas throughput;
- load may be transferred from other plants to a large existing acid plant.

Increasing capacity can be realised by either increasing the gas concentration or increasing the gas flow rate. A number of acid plants run close to the practical limit of $SO_2$ concentration of 12 to 13% to the first pass (which is a limitation given by the catalyst operating temperature). Other plants may benefit from increasing the $SO_2$ concentration, which often requires upgrading the catalytic converter to increase the conversion capacity without increasing environmental emissions. In most cases, reducing the gas-side flow resistance and upgrading catalyst is the standard procedure. Specific details are part of the tricks of the design engineer's trade. Solutions often consider: replacing equipment that cause process bottlenecks, use of low pressure drop equipment (such as improved catalyst, and also low pressure drop equipment).

## Project execution strategies

Many aspects should be considered in the development of a project execution strategy. The following is a desirable basis for a plant upgrade:

- new equipment to allow for lower emissions of $SO_2$ to the environment (often, replacement of the catalytic converter is required);
- new equipment to have lower pressure drop, thus saving energy consumption of the main blower;
- new equipment to be fabricated utilising better materials than existing;
- new equipment to be safer and more ergonomic than existing;
- new equipment having a robust mechanical design and to provide better reliability, higher on stream time and lower maintenance requirements than existing. Elimination of gas leaks is also important;
- specific dimensional limits to be maintained to comply with specific client requirements;
- specific tie-points to be matched to minimise ducting and piping changes;
- re-use existing foundations when possible;
- fabricate as much as possible in shop; ship to site in one piece if possible;
- design for adequate seismic conditions.

The plant upgrade can be completed in one stage, or in multiple stages lasting several years. It is often convenient to upgrade the plant in stages to achieve all design objectives with minimal disruption to plant turnaround schedules and lower upfront capital investment. At the time of a plant upgrade, some key decisions should be made to decide the equipment configuration and location of the new systems. For instance, plant owners may consider replacing equipment in the same location or in a new location. Deciding the location of the replacement equipment is one of the most defining factors of the total project cost. In practice, re-use of existing foundations, piping, ducting and rotating equipment can significantly reduce the total project cost. Selecting the type of equipment is also important. However, this is often limited by the mechanical condition of existing equipment.

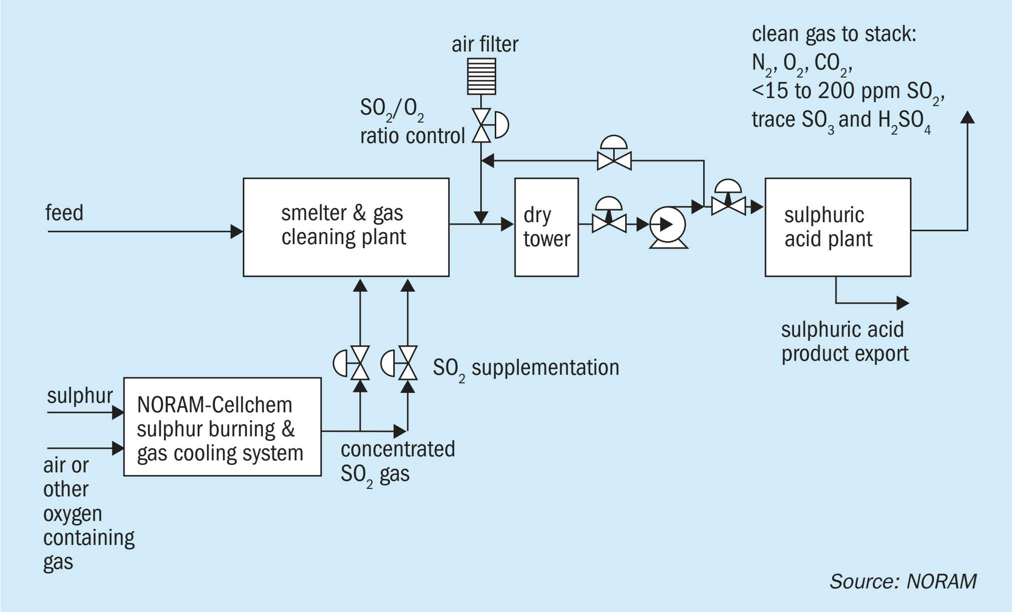
## Stabilisation of metallurgical acid plants

For metallurgical sulphuric acid plants, the $SO_2$ concentration in the feed process gas typically varies between 6 and 13% (mol/mol). Depending on the upstream smelting process, and the use of continuous or discontinuous furnaces, the concentration of $SO_2$ can fluctuate and, in some cases, reach concentrations below the plant autothermal limit. If the $SO_2$ concentration is low, the temperature of the converter beds may be too low to achieve adequate conversion and the emissions of $SO_2$ to the environment may increase, it may be difficult to maintain the plant water balance, and the product sulphuric acid may get diluted. In some cases, plants spend large amounts of fuel to provide heat using a process heater (the use of this heater increases operating costs and emissions of $CO_2$ and NOx). Moreover, the fluctuations in $SO_2$ concentration cause changes to the plant temperature profile and expose the equipment to thermal expansion and contraction that may cause premature equipment failure. Also, the net acid production decreases.

Several strategies have been developed to eliminate the effects of the fluctuations in total gas flow and $SO_2$ concentration, they include:

- Smelter design changes – some smelting technologies have fewer fluctuations in the $SO_2$ gas than others.
- Tail gas scrubbing and absorption-desorption technologies – these technologies can be used to treat low concentration $SO_2$ gases and fluctuating gas feeds.

Fig 1: **Schematic representation of $SO_2$ supplementation in a metallurgical acid plant**




*Source: NORAM*

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60

- Supplementation of $SO_2$ – the simplest strategy, resolving the issue by supplementing only the amount of $SO_2$ needed to maintain stable operation of the plant.

## NORAM's $SO_2$ supplementation strategy

Supplementation of $SO_2$ to metallurgical plants can be used to stabilise the feed to the acid plant, in particular during the periods of low $SO_2$ concentration. This strategy of supplementing $SO_2$ when it is needed combined with a sulphur burner system that allows for turndown rates as low as 10% of the maximum rate, provides maximum flexibility, simplicity and cost effectiveness. Project payback can be measured in terms of improved plant reliability, reduction in emissions to the environment, savings in heating fuel, increased productivity, increased equipment longevity, and overall capacity increase.

Fig. 1 shows a schematic representation of $SO_2$ supplementation in a metallurgical plant. A single NORAM-Cellchem sulphur burner can be used to supplement $SO_2$ to several sulphuric acid plants running in parallel. The $SO_2$ supplementation system can allow for stable and reliable operation of all acid plant trains even when the smelters are operating under upset conditions.

The utilisation of $SO_2$ supplementation can increase the reliability of the acid plant. The main reason for this reliability increase is that, with the implementation of a sulphur burner system, the plant can operate with a constant temperature profile since all catalyst beds would have a constant outlet temperature. The risk of premature equipment failure is also reduced.

A plant with a constant temperature profile would last much longer than one with large variations in temperature. For this reason, sulphur burning sulphuric acid plants have stable operation and require less frequent equipment maintenance and equipment replacement (typically sulphur burning plants can operate for two to three years without shutting down, while metallurgical plants typically require maintenance shutdowns every year).

The proposed method of stabilising the $SO_2$ feed to the plant requires a relatively low capital investment compared to other alternatives. The main equipment required includes a sulphur burner, and a quench tower or a waste heat boiler, and sulphur storage equipment.

The sulphur burner system is likely to have an operating cost advantage over other process alternatives.

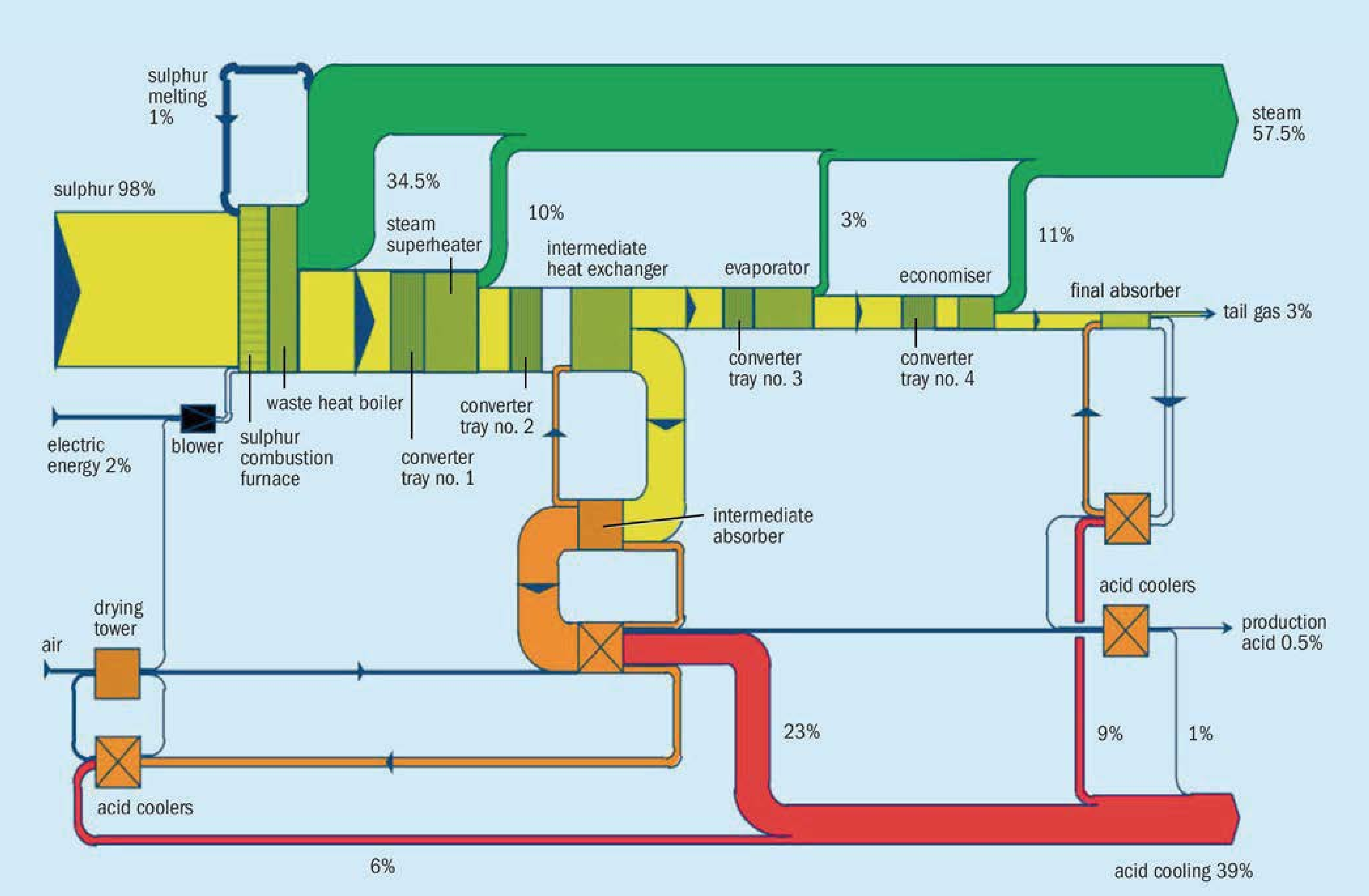
The sulphur burner system effectively decouples the performance of the acid plant from the performance of the upstream smelter. This makes the operation of the acid plant much easier for the plant operators.

Another positive consequence of the implementation of a sulphur burner system is that the yearly acid and steam production rate increases. The amount of additional acid produced can be controlled depending on commercial considerations and the operation of the acid plant.

## Outotec energy efficiency improvements

Energy efficiency improvement projects are of strategic importance and can lead to valuable opex savings for operating companies, subject to operating condi-

Fig 2: **Sankey diagram of a typical sulphur burning plant without heat recovery**




Source: Outotec



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tions and local energy prices. Considering low pressure steam generation from the heat available in the intermediate absorption section is of particular importance. The financial efficiency of such an option is very high with break-even points of less than three years.

It should however be noted that the operation of such a heat recovery system has to be considered in context with the sulphuric acid plant as a whole and in particular potential negative impacts. Increasing energy efficiency via heat recovery systems should not come at a cost to the overall operating plant financial efficiency.

Industry efficiency is most often considered to be connected with energy usage only. Other aspects are revealed when looking at the definition of the word: "doing something well and thoroughly with no waste of time, money or energy".

Thus efficiency in an industrial setting demands that all aspects need to be considered, including the omnipresent financial considerations – the profitability of a plant.

Energy efficiency is defined as

$$\eta = \frac{P\ out}{P\ in} \quad or \quad \frac{E\ out}{E\ in}$$

With regard to a sulphuric acid plant, the work or energy on the input side is the feedstock and mainly relates to electrical energy, as can be observed on the left side of the Sankey diagram of a sulphur burning plant detailed in Fig. 2.

On the output side, the product as well as cooling water, tail gas and steam need to be considered. There is also a need to critically analyse and differentiate between useful and waste energy.

Based on Fig. 1, the energy efficiency ($\eta$) can be estimated as 58% for a plant without heat recovery from the acid side. It can also be seen that energy losses to cooling water (as waste heat) account for up to 39% of the available energy, thus efficiency improvements are a realistic possibility.

## Profitability – financial efficiency

A very simple method to determine the financial efficiency of a certain project is the efficiency ratio, which simply calculates the operational expenses in relation to the revenue. For a hypothetical project which needs to spend €50 to produce a product that will be sold for €100, the efficiency is 50%. This very simple performance figure is often helpful, but fails to take into account major capital expenditures that are often incurred at the beginning of a project. In order to obtain a financial efficiency ratio, whilst taking the whole project investment into consideration, the return on investment (ROI) should be considered.

$$ROI = \frac{(gross\ profit - expenses)}{investment} = \frac{net\ profit}{investment}$$

Following the above definition, the ROI for a project can be calculated per period or overall project lifetime by adjusting the net profit to the desired period. The investment sum in the denominator should however always be the total upfront investment sum.

## Heat recovery

Considering the energy efficiency concepts mentioned regarding areas for potential efficiency improvements, the amount of energy wasted as cooling water is significant. It appears therefore logical to improve the overall energy efficiency by implementing a heat recovery process, such as the HEROS™ process.

As heat transfer to cooling water usually occurs at an energy level characterised by low level temperatures, special process measures have to be taken to convert the energy to a valuable product. Besides hot water generation for applications such as district heating, generally low pressure steam generation (up to 10 bar g) is the most versatile option.

This process requires the generation of very hot sulphuric acid, which involves certain process/technical risks associated with the acid plant installation. Fig. 3 depicts a typical plant configuration of a HEROS™ system, including a venturi absorber, a second stage absorption tower, as well as a pump tank connected with a heat exchanger for low pressure steam generation by cooling highly concentrated, hot sulphuric acid.

It should be noted that all process equipment, instrumentation and control logic associated with the HEROS™ configuration was specifically designed for production risk minimisation and mitigation.

The inclusion of the HEROS™ system into a metallurgical or sulphur burning sulphuric acid plant can be performed as part of a green field project or as a retrofit into an existing plant. For retrofitting applications, construction becomes a very important issue – due to the unique plant configuration, the construction, checking and pre-commissioning of the HEROS™ system is possible during full operation of the existing plant. Shutdown times for the tie-in is therefore reduced to the bare minimum.

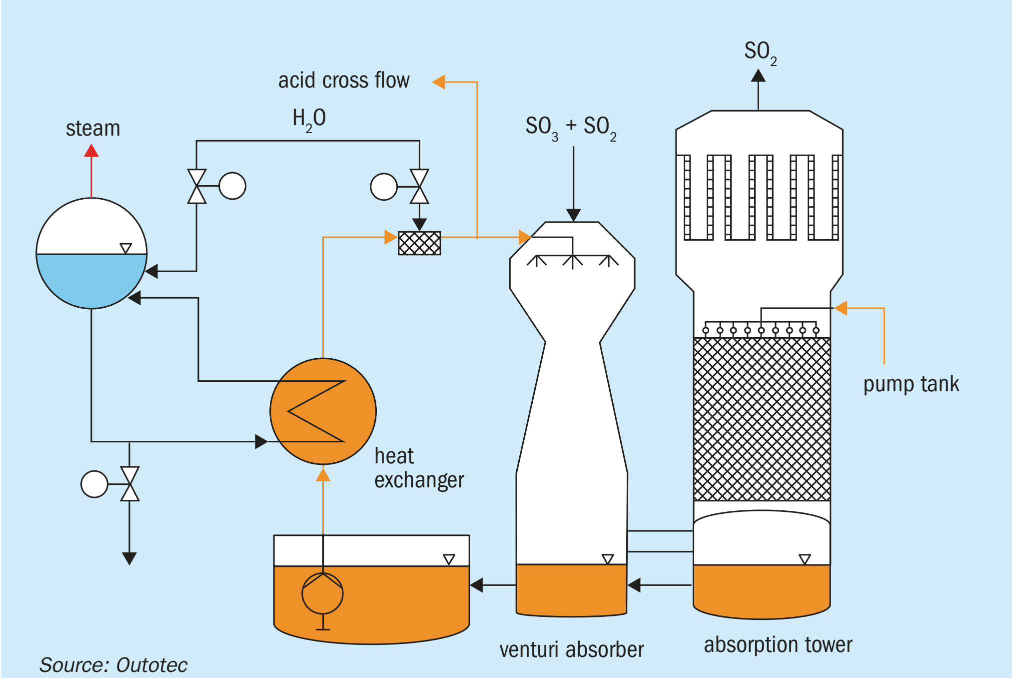
## Efficiency considerations

The absolute thermal efficiency increase typically associated with the installation of a heat recovery system in the intermediate absorption section amounts to 21%, leading to an overall plant efficiency of 79%.

To assess the holistic efficiency of such a project, the financial efficiency has been reviewed considering the following design basis as shown in Table 2.

The financial efficiency of a HEROS™ system based on the above design basis

**Fig 3: HEROS™ plant configuration**



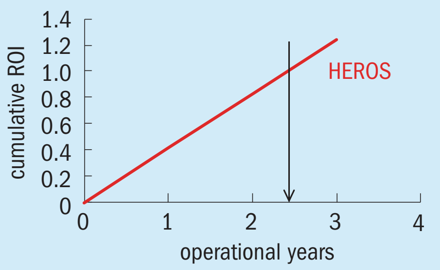

*Source: Outotec*

**Table 2: Design basis for a financial efficiency calculation**

| | |
|---|---|
| Plant capacity | 4,500 t/d $H_2SO_4$ (as 100 wt-%) |
| Plant location | Europe |
| Plant type | Sulphur burning, 3+1 |
| Utility concept | "Over the fence" – purchase of electricity, cooling water, demin water and LP steam. Sale of HP and LP steam. |
| Financial concept | Plant cost fully financed by a commercial loan: interest rate 6%, depreciation based on a 20 year period. |

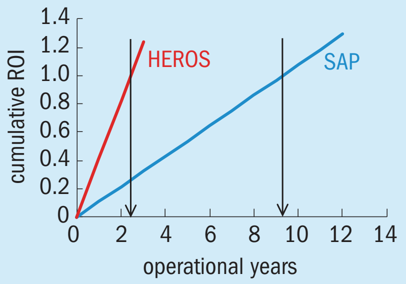
*Source: Outotec*

**Fig 4: Cumulative ROI of a HEROS™ system**



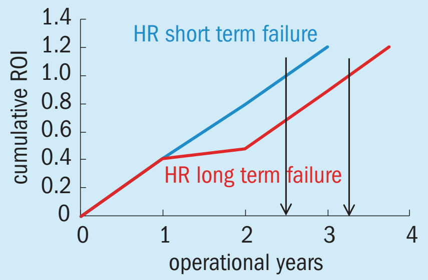

*Source: Outotec*

**Fig 5: Cumulative ROI of a sulphuric acid plant (SAP) and a HEROS™ system**



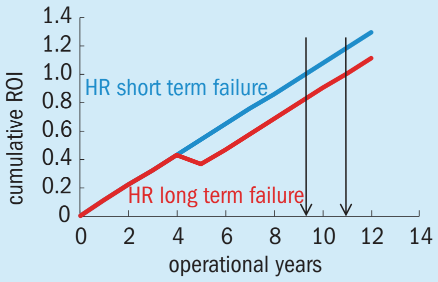

*Source: Outotec*

**Fig 6: Cumulative ROI of a heat recovery system impacted by a failure**




*Source: Outotec*

**Fig 7: Cumulative ROI of a sulphuric acid plant (SAP) impacted by a HR failure**




*Source: Outotec*

is considered by calculating the ROI on an annual basis. With an annual ROI of 0.44, the investment can be considered as highly efficient.

Fig. 4 shows the cumulative ROI for the HEROS system. The timeframe after which the cumulative ROI equals 1.0 designates the break-even point of the project, which is reached after 2.4 years in this particular case.

Considering the strong energy efficiency increase, coupled with the outstanding financial performance of the demonstrated heat recovery project, the recommendation to implement this solution should be very clear.

## Lifetime effects – failures

During the lifetime of technical plant and equipment, there is a certain probability of a failure occurring. Often preventive maintenance (PM) or reliability-centred maintenance (RCM) is performed to increase the reliability of equipment involved, nevertheless, the risk of failure (of a boiler, for instance) cannot be reduced to zero without incurring significant costs.

To illustrate the effects of an unexpected equipment failure, a second financial efficiency calculation needs to be performed using the same design basis as above, also considering the ROI of the sulphuric acid plant itself. Fig. 5 details the development of both projects with break-even points after 2.4 years and 9.3 years respectively, based on failure-free operation.

Figs 6 and 7 illustrate the development on the same design basis, but considering the failures detailed in Table 3 for a non-specific heat recovery system.

Both scenarios require the heat recovery system to shut down, albeit for different durations due to the nature of the failure mode and the involved repairs. Accordingly, the additional cost for spare parts and repair work is considered.

Whilst the acid pump failure is resolved within a fairly short timeframe, the boiler leakage scenario leads to dilute acid at very high temperature, which results in severe corrosion rates. Possible damage to further equipment is very likely, leading to an overall shutdown of the plant for three months for repairs.

For these scenarios, the break-even point of the heat recovery system extends to 2.5 and 3.25 years respectively. Regarding the efficiency improvement related to the project, the break-even after approximately 3 years in the case of the long term failure is still perfectly acceptable.

At the same time the effect on the operation and financial performance of the sulphuric acid plant as a whole needs to be considered. Effects on ROI and break-even by the short term failure are negligible, as long as these are not repeated failures. In contrast, the long term failure leads to a production loss of three months in the operational year in which the failure occurred, which results in significant

**Table 3: Heat recovery (HR) failure scenarios**

| | Short term failure | Long term failure |
|---|---|---|
| Failure mode | Acid pump failure | Boiler leakage with weak acid scenario |
| HR shutdown duration | 3 days | 3 months |
| Additional cost (% of initial investment) | 3% | 20% |

*Source: Outotec*

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Table 4: **Risk mitigations for heat recovery systems**

| | | | **HEROS™ feature** |
|---|---|---|---|
| **Availability** | Material of construction | All vessels are acid brick lined to minimise corrosion. Use of Alloy 3033, which allows for wide operational window where no brick lining is possible. | Yes |
| | Flow sheet | Fundamental principle is that HR plant failure will not lead to SAP plant shutdown. The hot acid circuit is completely separated from rest of the acid plant. Intermediate absorption tower is designed for complete $SO_3$ absorption at 100% plant load. | Yes |
| **Safety** | Flow sheet material of construction automation | In fail-safe mode, automatic draining of hot acid by gravity into brick lined equipment, reducing corrosion to minimum levels. | Yes |
| **Operability** | Support tools | PORS system for additional high level trending/critical process information requiring operator action to safeguard operating plant integrity. Operator training simulator as optional training measure. | Yes |

*Source: Outotec*

financial losses. In terms of cumulative ROI, this sets back the break-even point of the sulphuric acid plant to 11.0 years.

Taking into consideration the magnitude of the capital investment of the heat recovery system compared to that of the sulphuric acid plant, this setback (of almost two years) is immense.

## Outotec mitigation principles

Considering the long term failure scenario outlined and the list of critical system attributes/risk mitigation factors of a heat recovery system detailed in Table 4, the outcome of the financial impact is shifted back to the earlier scenario (no failure).

Even with a break-even point after approximately 3 years for the HEROS™ system due to a potential boiler failure, the break-even point for the sulphuric acid plant will remain unchanged at the initial 9.3 years, thanks to Outotec's unique risk mitigation principles, whereby the operability of the acid plant is not affected. This vast improvement in operational efficiency is directly attributable to the specific flow sheet features, which allow operation of the sulphuric acid plant at full capacity, full high pressure steam production, even with the HEROS™ system in shutdown mode.

Certainly other risk mitigation factors, such as the chosen material of construction should also be highlighted. Hydrogen incidents, nowadays widely acknowledged in the acid industry are mitigated by the incorporation of brick lined HEROS™ vessels, thus reducing corrosion levels to an absolute minimum and providing inherent safety for the operating personnel. In a world of ever increasing electronic warnings, operators are becoming numbed to the flashing lights and buzzers informing them that some part of the plant requires attention. There is however a need for high level trending/critical process information requiring operator action to safeguard the integrity of the operating plant. Outotec have therefore developed a plant operability reliability and safety system (PORS) to meet these requirements and a module can be found at the centre of the HEROS™ system.

In short, it is critical to consider energy saving process technologies that have attempted to mitigate technical risks of potential failure and that do not negatively impact the ROI of the overall plant.

# MECS case study

## Cutting $SO_2$ emissions while increasing fertilizer production

This case study describes how LLC IG Phosphorit is set to raise the output at its sulphuric acid production plant located in Kingisepp, Russia to over one million t/a with the help of MECS.

In 2001, when LLC Industrial Group Phosphorit (IG Phosphorit) became part of the Mineral and Chemical Company, EuroChem (MCC EuroChem), the group began carrying out a large-scale reconstruction of the industrial processes at its plant in Kingisepp near St. Petersburg (Russia). The main driving force for the reconstruction was a projected increase in mineral fertiliser production capacity along with a simultaneous reduction in industrial emission levels. Between 2001 and 2005, production capacity for sulphuric acid at IG Phosphorit's sulphuric acid plant (SAP) increased from 450,000 to 700,0000 t/a. MECS began working with IG Phosphorit in 2005, supplying the Kingisepp site with highly efficient Brink® mist eliminators for its drying and absorption towers, which helped to solve the problem of acid mist and droplet carry-over. During 2007-2008, IG Phosphorit launched a gradual systemic revamp programme for the SAP based on MECS know-how, in order to achieve a final sulphuric acid performance capacity of 1 million t/a.

A few years later the goal was within reach. As Mr Sergey Sheibak, Technical Director of the IG Phosphorit plant, said: "In 2015 MECS specialists conducted a technical audit to evaluate opportunities to further enhance the performance of the SAP by at least 10%. Their report clearly showed the presence of hidden production increase reserves. We should be able to reach an output of 1,122,000 tonnes of sulphuric acid per year and, at the same time, reduce the number of equipment units to generate steam from five to three. These three pieces of steam generating equipment should allow us to reduce the pressure drop across the plant from 1,800 to 800 mm water column, which would give us the opportunity to improve performance while maintaining the existing emissions."

These further changes came on the back of the steps already taken by IG Phosphorit over the previous ten years to increase plant production and reduce emissions. Apart from supplying equipment, MECS carried out engineering studies (ducting, steel structure, 3D model), provided process design and supported IG Phosphorit with advisory services for site installation, commissioning and start-up. SNC Lavalin was tasked with detail design and project execution.

Thierry Marin, managing director MECS explains: "One of the key requirements from IG Phosphorit was to help the group to comply with the new MCC EuroChem sustainability goals. The first goal focused on energy recovery, and the introduction of a new MECS® Heat Recovery System (HRS™) helped the site recover 20% additional energy that previously had been wasted. The second aspect of the sustainability goals concerned the $SO_2$ emissions. To address that, we developed and improved the conversion rate of the IG Phosphorit plant in Kingisepp. This represents a real step change for the site."

## Efficiency improvements on all fronts

Mr Sheibak provides more detail of the long-standing project: "We initially replaced the converter, the sulphur burner and the gas-gas heat exchangers. To enhance the functionality of the sulphuric acid plant operation, a new stainless steel converter was installed. This has allowed us to save almost a day of production time, which was previously lost as a result of plant shutdowns for repair and time needed to put the plant back into operation".

The deputy head of the sulphuric acid production plant, M. Aleksandr Smirnov, sums up the revamp since 2008: "I have been working in this plant for more than 10 years, and I was given an outstanding opportunity to participate in all stages of the revamp over the last 10 years. During this period, the plant underwent repeated reconstruction followed by an increase in production capacity from 450,000 tonnes of sulphuric acid per year (the initial capacity of the plant) to 700,000 tonnes. MECS has played a big role in our project and helped us to increase our production rate even further from 700,000 to one million tonnes."

The sulphuric acid plant revamp continued in 2010. IG Phosphorit replaced two absorption towers: a drying tower and final tower, with all tower internals coming from MECS including the acid distributors and support grids. Next, IG Phosphorit decided to replace the interpass absorbing tower, called the "A1", and install a new tower with an HRS™ designed by MECS. Mr Valery Degtyarev, head of the sulphuric acid plant, points out: "The resulting efficiency gains were impressive." He says: "With the start-up of the HRS™ system, we have received an additional 70 tonnes of steam at 10 bar and were able to solve a number of problems. We no longer use boilers to produce steam at 10 bar and do not burn natural gas for this. Steam obtained through the HRS™ allows us to meet the needs of the site, avoiding the use of additional resources and extra costs for the purchase of natural gas."

Mr Smirnov explains further: "With the launch of the HRS™ system in 2012, the heat from absorption, in the form of medium-temperature steam, is sufficient to cover the needs of the entire plant. The steam is also used by our structural subdivisions."

All the high-pressure steam produced by the waste heat boiler installed after the sulphur furnace is used to generate electricity, and this allows IG Phosphorit to export an average 2.5 MW of power to the external network.

Maxim Petrov, director of maintenance and repairs at the Kingisepp site, is happy that the boiler system has also been updated: "For over 10 years we had a system consisting of two boilers made in Poland and the Ukraine, but this did not provide the HP steam performance we wanted. So we replaced both boilers with a single boiler supplied by MECS and manufactured by Thermal Systems (India) that offers a capacity of 150 ton/h.

The boiler was commissioned in October 2016 according to plan and is much easier to operate than our previous two boilers. With the support of MECS specialists, it was then directly brought up to design capacity and has to date operated at design load."

## Lowering emissions and saving time

The benefits of the revamp that IG Phosphorit has undertaken are not limited to high performance and efficiency. Changes in technology and equipment also led to a reduction in emissions. Mr Sheibak points out: "We are working at a capacity of 2,940 t/d without exceeding the permissible emissions limit. With the standard rate of emissions limited to 0.05 g/m³, we are currently working at an emission level of 0.017 g/m³."

"In accordance with the feasibility study carried out in 2015/2016 by MECS," he continues, "it seems possible to increase the production rate of the SAP to 1.122 million tonnes of sulphuric acid per year (3,300 t/d), while reducing $SO_2$ emissions from the current value of 417 ppmv to 132 ppmv (conversion rate of 99.9%). This modification should be carried out in the next few years."

Mr Sheibak concludes: "Our cooperation with MECS will continue, and we will realise the hidden production reserves identified during the audit in 2015/2016."

As Mr. Marin says: "The aim of MECS from the outset was to enable IG Phosphorit to realise its target production capacity efficiently, reduce emissions and recover energy in a sustainable manner. This the project has now achieved."


*IG Phosphorit's sulphuric acid plant in Kingisepp, Russia upgraded with the help of MECS for enhanced functionality, productivity and environmental performance.*

## Topsoe catalyst operating strategies

At a time when the pressure is high on sulphuric acid plant operators to reduce costs and improve profitability, changing the strategy for how the plant is operated has the potential of improving plant profitability, both in the short term and the long term with little or no investments required.

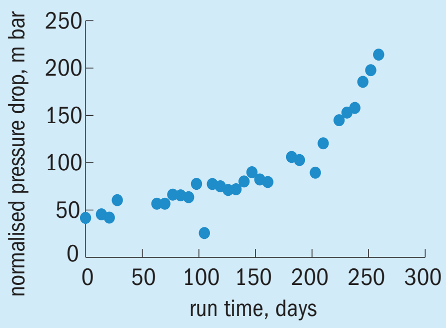
The choice of catalyst and how it is operated may influence the economics of sulphuric acid plants in a number of different ways. Campaign length can be improved, resulting in less downtime, turnaround costs and catalyst losses. Downtime and fuel consumption may be reduced by using the right catalyst and knowhow. Power consumption can be reduced by reducing plant and catalyst pressure drop, saving on energy costs. Finally, scrubber chemical consumption can be lowered by improving the conversion over the converter, resulting in savings on both chemical costs and potential by-product disposal.

To showcase how different catalyst-related questions may influence the profitability of the plant, examples from two different scenarios, partly based on different plant data, are presented.

### High pressure drop build-up rate

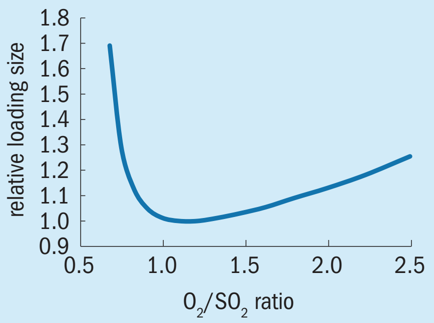
The first scenario revolves around a problem with rapid pressure drop build-up over the first bed of a 2,400 t/d sulphur burning

**Fig 8: Bed 1 pressure drop for a 2,400 t/d sulphur burning plant**




Source: Haldor Topsoe

**Fig 9: $O_2/SO_2$ ratio and catalyst vol. required to meet a fixed conversion**




Source: Haldor Topsoe

plant and the negative effect this had on the turnaround frequency. The high pressure drop build-up rate forced the plant to shut down every nine months to screen the catalyst in the first bed, as the blower could no longer maintain full gas flow. The pressure drop trend for the plant can be seen in Fig. 8. The situation was unacceptable, and a solution to the pressure drop build-up rate needed to be identified.

## Stronger feed gas

A very intuitive way of reducing pressure drop is to reduce the gas flow going through the plant. Obviously, simply reducing the gas flow without changing anything else will not be very attractive to the operator of the plant, as it will simultaneously reduce the capacity to the same degree. A way around this issue is to compensate the capacity lost due to lower gas flow by increasing the gas strength. Unfortunately, it is not that simple, as the performance of the catalyst beds need to be upgraded if the conversion is not to drop when the $SO_2$ strength of the feed gas is increased.

The $SO_2$ strength which can be operated with and still maintain a stipulated emission level, is dependent on the catalyst activity and available bed volumes. Until the minimum inlet temperature of the catalyst is reached and as long as room for more catalyst is available, the $SO_2$ can be increased, and $O_2/SO_2$ ratio decreased, while maintaining the same emission by adding more catalyst according to Fig. 9.

There are two main drawbacks of adding extra catalyst to allow the plant to operate at lower $O_2/SO_2$ ratios, the most obvious being that finally there is no more room, and secondly, the extra catalyst volume offsets some of the pressure drop reduction.

On the other hand, using more active catalyst to allow lower $O_2/SO_2$-ratio does not require room for more catalyst and will not result in any significant pressure drop increase that offsets some of the gains of the lower ratio. In case some of the catalyst loaded in the plant is old, deactivated or of lower quality, the higher activity may be achieved simply by replacing some of the catalyst with new high-quality standard catalyst. In case a significant improvement is necessary, it is however likely that only replacing the current catalyst with new standard catalyst will not be sufficient. In these cases, replacing the catalyst with high-activity caesium catalyst or even more advanced LEAP5 catalyst will probably be necessary.

Switching from standard catalyst to the same volume high-activity caesium catalyst in the final bed of a 3+1 DA plant will allow a sulphur burning plant to achieve the same conversion even when increasing the $SO_2$ from 10.0% to 11.5%. An increase from 10% $SO_2$ gas to a 11.5% $SO_2$ gas strength will reduce the gas flow by 13% if the production is kept constant. A 13% reduction in gas flow will in turn yield a reduction in plant pressure drop of some 20%, which for the example plant would not only increase cycle length, but also reduce the power usage by around 5.5 GWh yearly, corresponding to €650,000 with central European energy prices.

For other plants, using the higher $SO_2$ strength to achieve higher production without increasing the gas flow rather than lower pressure drop, may have an even greater effect on plant profitability. 15% higher $SO_2$ strength will correspond to 15% higher production from the same plant with the same blower, however, that will require an increased catalyst volume, even if one switches from standard to caesium catalyst. If the catalyst volumes are maintained, switching from standard to caesium catalyst would allow an increase in $SO_2$ strength, and thus also production, of 12.5% with unchanged conversion.

## Dust protection catalyst

Although decreasing the feed gas flow through use of higher feed gas strength will improve campaign length slightly through reducing the overall pressure drop, it will not address the underlying cause of the pressure drop problem – the dust deposition. Actually reducing the amount of dust that enters with the feed gas would be possible through upgrading the sulphur and air filtration for the sulphur burning plant (or gas cleaning section for a metallurgical plant), however, that may require a substantial investment, which could be hard to justify in the current financial climate. A solution that targets the dust issue directly, but does not require any substantial investment, is installing a layer of dust protection catalyst on the top of the first bed. Installing dust protection catalyst has the added advantage of being possible to do with very little preparation and requires very little time to carry out. It could therefore be implemented during the next shutdown.

Dust protection catalyst will not reduce the amount of dust coming in with the feed gas. It will allow more dust to deposit in the bed before the pressure drop increase. The larger dust capacity is achieved through using larger catalyst pellets to increase the penetration depth of the dust particles. Increasing the catalyst pellet size from 12 to 25 mm will increase the penetration depth by 100%, in turn also increasing the dust capacity and cycle length by the same amount.

Once the dust protection catalyst has been installed in the client's plant, the cycle length is improved greatly, saving the client significant sums in lost production and turnaround costs. A comparison between before and after the dust protection catalyst is installed, is shown in Fig. 10.

From Fig. 10 it can be seen that the improvement in campaign length is close to the 100%. Over a ten-year period, the longer campaign length would result in a decrease in the number of necessary turnarounds for catalyst screening from 13 to 6 and, assuming that ten days are required for a turnaround focused on screening bed 1, add another 70 production days. Furthermore, each shutdown that can be avoided will result in further savings in costs for screening contractors, make-up catalyst and fuel for start-up and purge.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46
47 48 49 50 51 52 53 54 55 56 57 58 59 60

## Lower power consumption

Even though the plant in the example was limited by the pressure drop build-up over the catalyst and therefore could fully utilise the larger dust capacity to achieve increased campaign length, other plants may have other bottlenecks that make a longer campaign length impossible. However, even these plants may benefit from installing dust protection catalyst though lower average pressure drop over the plant. To exemplify how such a plant could benefit from using the dust protection catalyst, a small calculation example is set up, based on the industrial data shown in Fig. 3. The energy savings achieved by a lower pressure drop can be calculated with the following formula;

$$Q=(G \cdot \Delta p \cdot 0.024)/0.7$$

Where Q is the difference in energy consumption per year [kWh], G is the flow rate [$Nm^3/h$] and $\Delta P$ is the pressure drop difference [mm Wc].

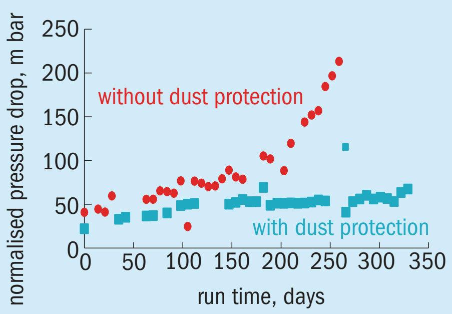
The difference in pressure drop is not constant over the campaign, so in order to be able to calculate the saving in energy consumption, the average pressure drop difference needs to be estimated. If a polynomial is fitted to the data and integrated, it can be calculated that the average pressure drop for the campaign without dust protection is around 10 kPa. If the same is done for the campaign with dust protection catalyst, this yields an average pressure drop of 4.5 kPa. The average pressure drop difference over a campaign is thus 5.5 kPa, or 560 mm Wc.

If the data pressure drop formula above is applied for the example plant, the yearly savings in power usage can be calculated to 4.0 GWh. With an average electricity price in the EU of 0.119 €/kWh, this corresponds to yearly savings of around €475,000.

The pressure drop increase rate seen in Fig. 10 is higher than seen in most plants, however, even if the same trend and data is applied to a normal two-year campaign, and assuming maximum pressure drop at the end of the campaign is 10 kPa, the reduction in power consumption can be significant. On average, the yearly reduction in power consumption will be some 1.65 GWh, corresponding to total savings of around €400,000 over the two-year campaign for the 2,400 t/d plant.

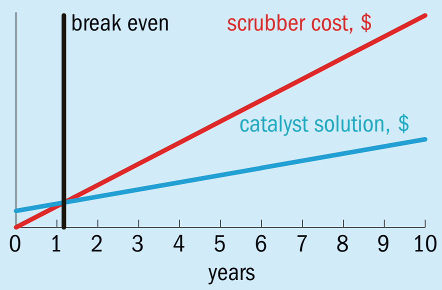
An important side-effect of adding dust protection catalyst to reduce the average pressure drop over the campaign, is the added dust capacity. The added dust capacity will reduce the risk of the plant having to shut down prematurely due to higher dust load than normally. In case of such an event, the dust protection will yield similar savings as presented for the example plant which has problems with short campaign length.

**Fig 10: Effect of using dust protection catalyst on pressure drop build-up over the first pass**




*Source: Haldor Topsoe*

**Fig 11: Scrubber and catalyst expenses with standard or caesium catalyst in final bed**




*Source: Haldor Topsoe*

## Higher activity catalyst for lower scrubbing costs

Some plants may have chosen to install a scrubber to cope with start-up emissions or potentially stricter steady state emission legislation. The scrubber chemicals necessary for the scrubber will have a significant negative effect on the operation expenses for the plant. In cases where a scrubber is installed, better catalyst solutions may often be disregarded since the imminent danger of exceeding the emission limits has been avoided. However, upgrading the catalyst loading may in many cases still pay off.

For a 1,000 t/d plant, switching from a standard catalyst to the same volume of caesium catalyst in the last bed will allow the conversion to be increased from 99.7% to 99.9%, corresponding to a reduction of the $SO_2$ concentration inlet a scrubber of 65%. The reduced $SO_2$ concentration inlet the scrubber achieved by the better catalyst solution equates to savings of close to 250 t of hydrogen peroxide or 580 t of caustic yearly in the scrubber. With a hydrogen peroxide price of 800 $/t and a caustic price of 500 $/t, the reduced scrubber chemical consumption corresponds in yearly savings to $200,000 and $290,000, respectively.

Although going for a caesium, rather than a standard catalyst loading, can be considered expensive, the extra cost can swiftly pay for itself through the reduction in scrubber chemicals (Fig. 11).

After just over one year, the savings exceed the extra cost, and over ten years of operation, the savings amount to seven times the extra cost. Although a life time for a final bed of ten years is a rather conservative lifespan for most plants, one implication of the swift return on investment is that even if there is an accident which results in the catalyst charge needing to be replaced, going with the caesium solution will still be economically favourable.

A potential added advantage of using a caesium solution is that, depending on the design of the catalyst loading and emission legislation, it may be possible to turn off the scrubber completely from time to time. This will free up operator time for other tasks in the plant. ■

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47 48 49 50 51 52 53 54 55 56 57 58 59 60

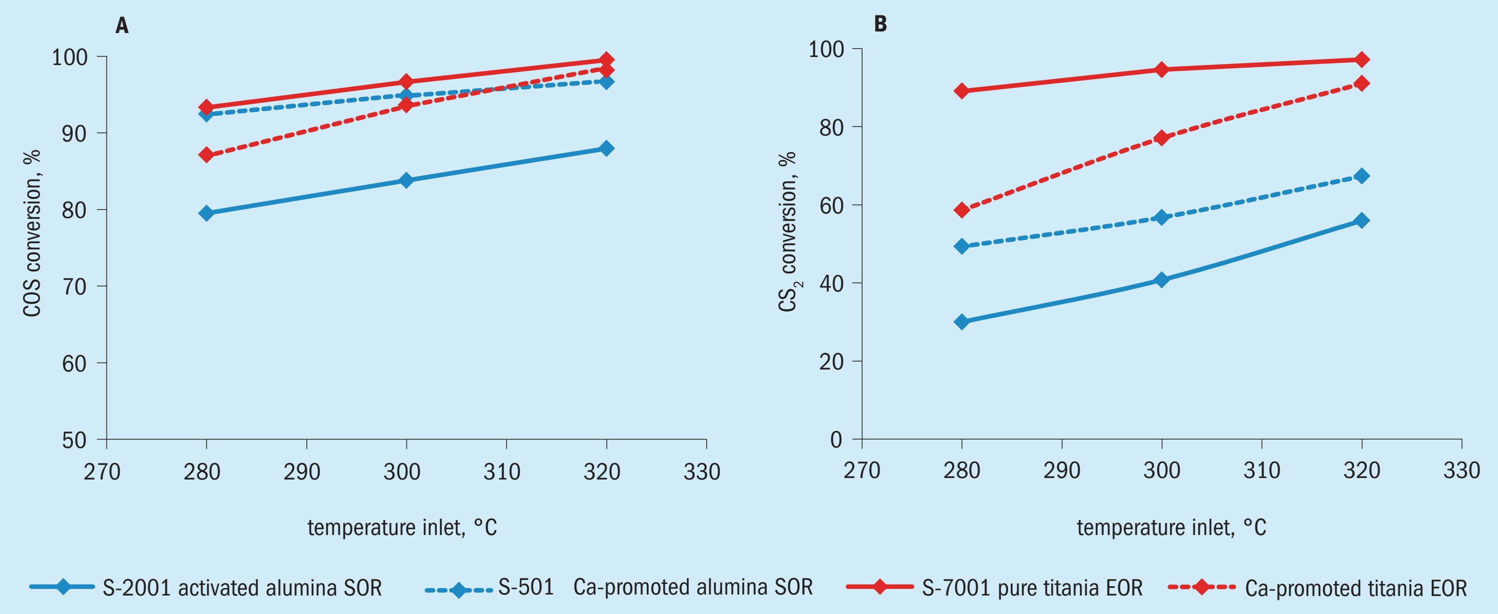
# The benefit of using titania in Claus and tail gas catalysis

Euro Support has developed and commercially produced a titania supported Claus tail gas hydrogenation catalyst designed specifically to operate at temperatures below 240°C in low temperature Claus TGTU systems. **B. Hereijgers, P. van Nisselrooij, B. van de Giessen,** and **M. van Hoeke** of Euro Support BV discuss the performance and benefits of this catalyst which has been tested under numerous conditions and compared with its commercially available alumina-based counterpart. In addition to significantly improved low temperature performance, the titania-based tail gas hydrogenation catalyst offers significant operational benefits in terms of start-up, resistance to gas contaminants and lifetime.

The modified Claus process is utilised worldwide to produce elemental sulphur by partial oxidation of $H_2S$. It consists of a high temperature combustion stage and a series of low temperature catalytic stages. In addition to $H_2S$ and $SO_2$, sulphur is also present in the form of COS and $CS_2$ in the Claus process. COS and $CS_2$ are formed in the furnace from CO and hydrocarbons and flow downstream to the catalytic reactors. In order to recover sulphur from these components, they need to be hydrolysed on the catalyst surface. $CS_2$ is more difficult to hydrolyse than COS.

Alumina and titania are the only metal oxides utilised in the field to promote the Claus reaction and the hydrolysis of COS and $CS_2$. Although it is well known that titania is a more effective catalyst than alumina for the hydrolysis of both COS

Figs 1a and 1b: **COS hydrolysis activity (A) and $CS_2$ hydrolysis activity (B) of different alumina and titania based commercial catalysts**




*Conversions for the alumina based catalysts apply to start of run, while the titania based catalyst were hydrothermally pre-aged to simulate end of run activity. Performance tests were carried out by Euro Support's R&D labs.*

and $CS_2$ and establishment of the Claus equilibrium, alumina remains the most extensively applied catalyst because of its relative cost. Besides having a lower activity than titania, alumina is susceptible to deactivation due to sulphation of the catalyst in the case of oxygen from a direct-fired reheater or the furnace burner entering the catalytic converter. Few operators are aware of the fact that when operated at an $H_2S/SO_2$ ratio below 2, e.g. when high concentrations of COS or $CS_2$ are present in the feed from the furnace, the alumina surface readily forms sulphate species and loses activity. At low temperature, as in the third Claus converter, an alumina catalyst is prone to deactivation by sulphation even under normal operation conditions.

Overall, titania is more suitable than alumina to be utilised in the modified Claus process. However, often titania is only applied as a bottom layer of catalyst in the first converter for cost reduction. One way to enhance the activity of the alumina catalyst for the hydrolysis reactions is by promoting the catalyst with calcium. Remarkably, the addition of calcium to a titania catalyst has an adverse effect and the hydrolysis activity decreases. Fig. 1 illustrates the relative activities of commercially available pure and calcium promoted alumina (start of run activity) and titania (end of run) catalysts for COS and $CS_2$ hydrolysis.

*Fig. 2: S-8001 titania based low temperature TGTU catalyst is provided as extruded trilobes.*

If environmental regulations stipulate emission restrictions beyond the capabilities of the Claus process, a tail gas treating unit must be considered. Claus effluent gas still contains several sulphur components, such as $H_2S$, $SO_2$, $S_x$, COS, $CS_2$ in the order of a few percent of the total stream. When applying a hydrogenation type tail gas catalyst, the aforementioned sulphur components are converted to $H_2S$. Through absorption by a selective amine the $H_2S$ is concentrated and returned to the front end of the SRU. Every sulphur compound that is not fully converted to $H_2S$ slips through the absorber and contributes to the $SO_2$ emissions of the plant. The classical hydrogenation/hydrolysis catalyst that is used is a combination of cobalt and molybdenum deposited on a spherical or extruded alumina carrier. The alumina carrier holds the CoMo nano-particles in their place to maximise the available CoMo surface area and the number of catalytically active sites. $SO_2$ and $S_x$ are hydrogenated on the CoMo particles (equations 1 and 2) whereas COS and $CS_2$ are hydrolysed on the catalyst carrier (equations 3 and 4). Besides the conversion of sulphur species, one other important function of the tail gas catalyst is the conversion of CO through the water-gas-shift equilibrium (equation 5). One advantage of this reaction is that it provides active surface bound hydrogen that enhances the hydrogenation reaction rates. On the other hand, the presence of CO contributes to the COS concentration through the sour-gas shift reaction (equation 6).

$$S_x(g) + H_2(g) \rightarrow H_2S(g) \quad (1)$$

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

$$COS(g) + H_2O(g) \rightleftharpoons H_2S(g) + CO_2(g) \quad (3)$$

$$CS_2(g) + 2H_2O(g) \rightleftharpoons 2H_2S(g) + CO_2(g) \quad (4)$$

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \quad (5)$$

$$CO(g) + H_2S(g) \rightleftharpoons COS(g) + H_2(g) \quad (6)$$

Fig 3: **Comparison of the new generation $TiO_2$ based TGTU catalyst to several commercially available alumina based counterparts after optimal activation of the catalysts**

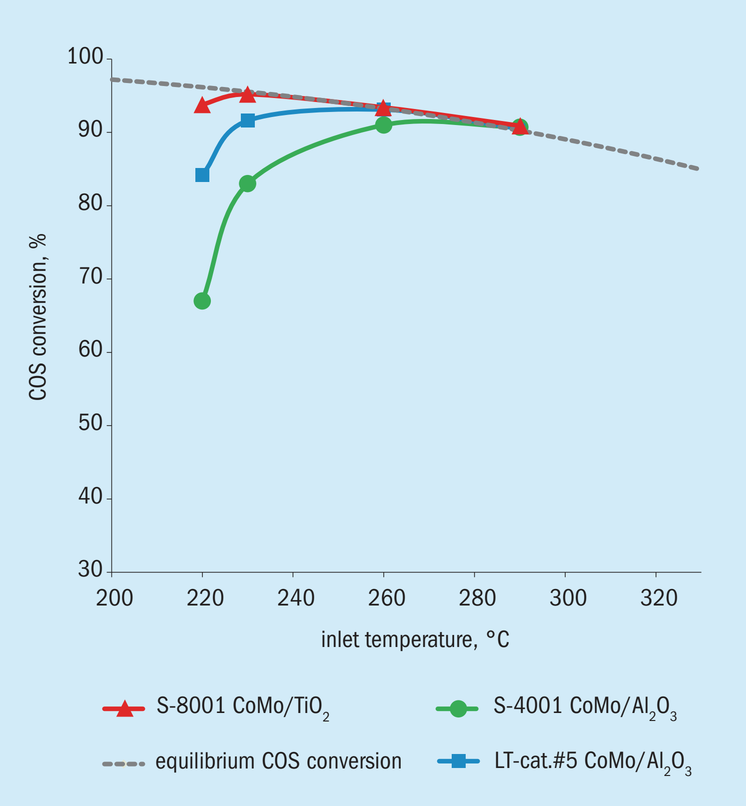
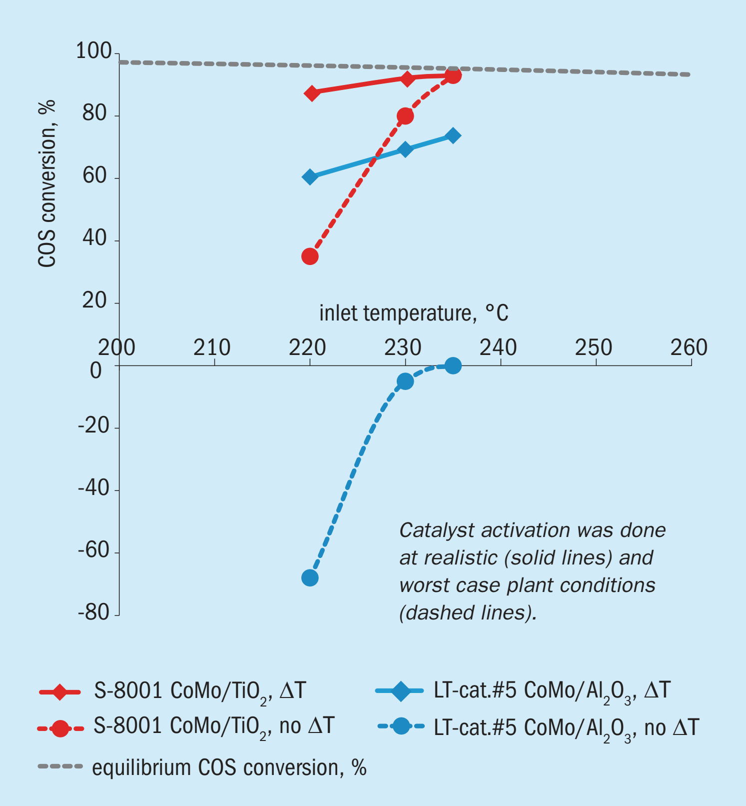



Fig 4: **COS conversion activity of $TiO_2$ based TGTU catalyst compared with its commercially available alumina based counterpart**



As in all catalytic processes the catalyst, over time, will deactivate. Most prone to deactivation are the CO shift (equation 5) and COS hydrolysis reactions (equation 3). A loss of shift activity causes more unconverted CO to remain and to react to COS through reactions equation 6 and equation 7. In combination with a loss in hydrolysis activity, the COS emission levels are bound to increase. A drop in COS conversion thus is the first sign of performance loss of a TGTU catalyst.

$$CO(g) + {}^{1}/_{8}\, S_8(g) \rightleftharpoons COS(g) \qquad (7)$$

Modern Claus plants that are equipped with TGTUs are nowadays increasingly based on a so-called low temperature hydrogenation process, e.g. the LT-SCOT technology as is licenced by Jacobs Comprimo Sulfur Solutions[1]. Characteristically, the LT-technology involves replacement of the in-line burner, annex reducing gas generator (RGG) by a steam reheater. The biggest advantage of the low temperature system obviously is a capital and utilities cost reduction, but also operational problems associated with in-line burners, e.g. sooting and oxygen slip are avoided[2]. The biggest challenge is that the temperature of the gas stream to the inlet of the hydrogenation reactor is limited to about 240°C instead of the 280-320°C in the high temperature lay-out[3]. This places special demands on the catalyst and new TGTU catalysts had to be developed that allow operation at such conditions.

In the Claus section of the SRU, a solution to the lower hydrolysis activity of the alumina catalysts has already been found years ago, in the use of a titania catalyst. The logical next step is to introduce the benefits that the titania catalyst offers in the Claus sections into the tail gas section of the process. Using a titania carrier to support the CoMo catalyst significantly improves the hydrolysis activity, and the catalyst is able to maintain this activity for a much longer duration and at lower temperature than is possible with an alumina carrier. The altered interaction between the active metals and the titania support has proven to also provide other operational benefits such as lower mercaptans formation, high oxygen resistance and easy (re)activation. Fig. 2 shows the new S-8001 titania based low temperature TGTU catalyst, provided as extruded trilobes.

## CoMo-titania properties and performance

### Experimental details

All experiments were performed in the same bench-scale reactor located at the Euro Support Manufacturing Czechia R&D labs in Litvínov, Czech Republic. The test reactor and preheater are made of glass and are inert for hydrogenation, oxidation and shift reactions at the employed conditions. In every test 70 ml catalyst is loaded into the reactor. Due to the size of the catalyst, the catalyst can be tested in its actual shape and no crushing is required. The test unit, including analysis, is automated and can operate autonomously and uninterrupted. The tail gas composition for the experiments consisted of 1.0 mol-% $H_2S$, 0.5 mol-% $SO_2$, 250 ppm COS, 250 ppm $CS_2$, 1.5 mol-% $H_2$, 1.1 mol-% CO, 16.7 mol-% $CO_2$, 22 mol-% $H_2O$ in $N_2$ at a gas hourly space velocity GHSV = 1,500 $h^{-1}$ STP.

The input and output gas are analysed by a customised on-line gas chromatograph specially designed to analyse sulphur compounds. Prior to analysis of the gas phase, elemental sulphur and water are removed to prevent plugging of the lines and establishment of the Claus equilibrium at a low temperature section.

Three different commercially available catalysts were used in this study:

- S-4001, CoMo on a spherical alumina support. Designed for operation at T > 250°C
- S-8001, CoMo on an extruded titania trilobe support. Designed for operation at T < 240°C
- LT-cat.#5, CoMo on an extruded alumina support. Designed for operation at T < 240°C

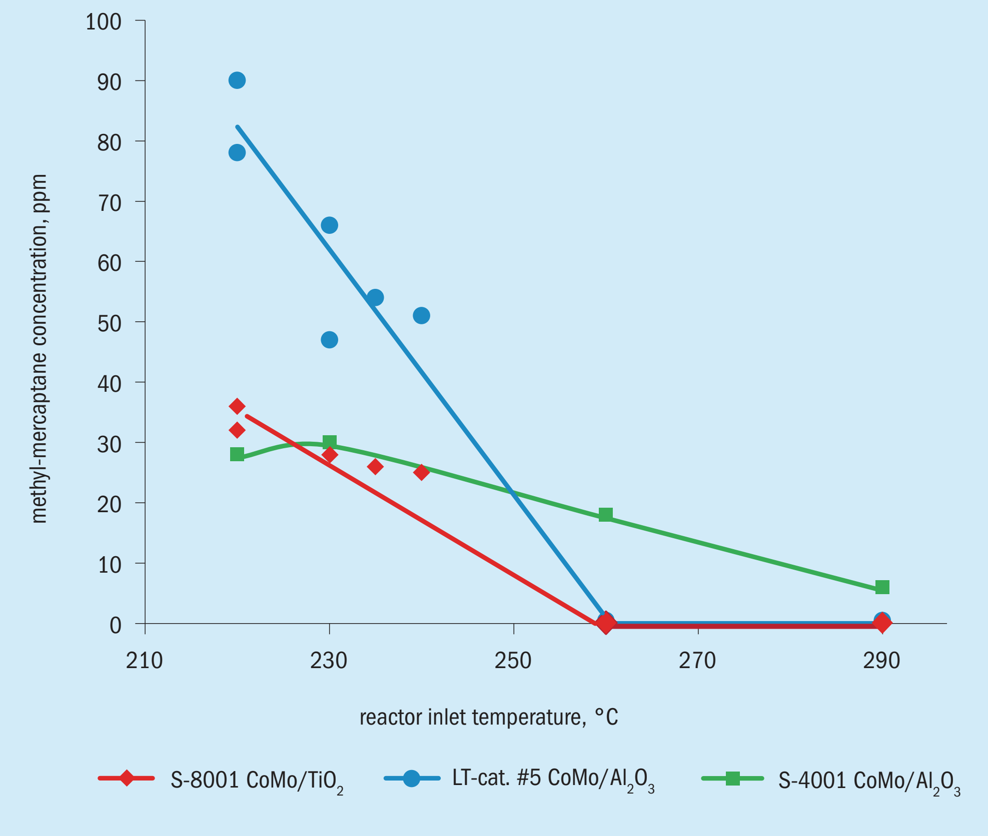
The CoMo weight loading for S-8001 and LT-cat.#5 is identical and somewhat higher than the CoMo weight loading of a classical TGTU hydrogenation catalyst, e.g. S-4001.

## Catalyst activation

Before a TGTU hydrogenation catalyst can be employed, it needs to be transformed into its active state. This means that the cobalt and molybdenum oxides need to be carefully transformed into their respective metal sulphides, $CoS_x$ and $MoS_x$. For the activation there are three approaches that are industrially applied.

- High temperature in-situ sulphiding in a gas mix containing $H_2S$ and $H_2$. Although this approach offers the best catalytic performance, it is expensive as it requires an external supply of pure $H_2S$ and $H_2$ (generally from gas cylinders) and difficult for the operator, as the temperatures are high (350+°C) and a lot of heat is generated which can potentially cause the reactor to overheat and destroy the catalyst. This approach only applies to TGTUs that have gas fired reheaters installed to obtain the required temperature.
- The advantage of in-situ sulphiding is that it is applicable even using steam reheaters that can provide a gas temperature of maximum 240-250°C. The moderate temperatures significantly reduce the risk of overheating the catalyst bed. The low temperature approach relies heavily on the heat that will be generated in the process to obtain a sufficiently high temperature in the catalyst bed[3].
- Ex-situ presulphiding is an approach offered for all of Euro Support's TGTU catalysts on the market and involves the pre-activation of the catalyst in a separate reactor. The activated catalyst then is stabilised so that it can be safely loaded into a reactor that is blanketed with nitrogen gas. The large benefit is that the catalyst is immediately ready and no difficult start-up procedure is required. The influence of this approach on the catalyst activity is beyond the scope of this article.

Fig 5: **Methyl mercaptan formation over titania supported low temperature tail gas hydrogenation catalysts compared with alumina supported low temperature and high temperature catalyst**




For reasons explained in the introduction, the best way to judge the overall performance of a TGTU hydrogenation catalyst is to evaluate its ability to convert COS, as this reaction is the first to become kinetically limited when the catalyst activity is low. Although the conversions of all other components are monitored in the experiments, comparing the COS conversion allows discrimination between high and low catalyst activities taking into account both the hydrogenation and the hydrolysis functions of the catalyst.

Fig. 3 shows the COS conversion over the new generation titania based CoMo TGTU catalyst compared with several commercially available alumina based counterparts after high temperature sulphiding, i.e. optimal conditions.

Clearly the conventional TGTU catalysts, such as S-4001, do not reach the equilibrium conversion at temperatures below 280°C. This immediately shows why this type of catalyst is not suitable for application at low temperature when only steam reheaters are present. The titania based S-8001 catalyst and its commercially available alumina-based counterpart both perform much better at low temperature than the conventional hydrogenation catalyst. However, when the temperature decreases to below 230°C, the $TiO_2$ support material offers a clear advantage over alumina.

Fig. 4 illustrates the performance of the titania and alumina based low temperature TGTU catalysts after in-situ activation at temperatures applicable to steam reheaters. In-situ activation relies on the heat that is generated by the exothermic sulphiding reaction. It was estimated that this reaction heat provides an exotherm resulting in a bed temperature of > 300°C[3]. When this 300°C is applied to the catalyst during the activation (indicated by "ΔT"), the titania catalyst exhibits a COS conversion activity almost similar to what is obtained for the optimal activation conditions. However, the alumina based low temperature TGTU catalyst lags behind. Even after a worst case activation procedure when insufficient heat is generated and the temperature in the bed does not exceed 240°C, the titania catalyst still outperforms the alumina based catalyst when operating at 230°C or higher. Under these worst case activation conditions the alumina catalyst turns into a net COS producer.

From the results it is evident that the titania supported CoMo catalyst offers a great benefit of easy and effective activation at low temperature when only steam reheaters are present in the TGTU.

## Mercaptan formation and conversion

One risk associated with the operation of the hydrogenation catalyst of a TGTU at low temperature is an increase in sulphur emissions through the formation of methyl-mercaptan by $CS_2$ hydrogenation (equation 8)[2].

$$CS_2(g) + 2\,H_2(g) \rightarrow CH_3SH(g) \quad (8)$$

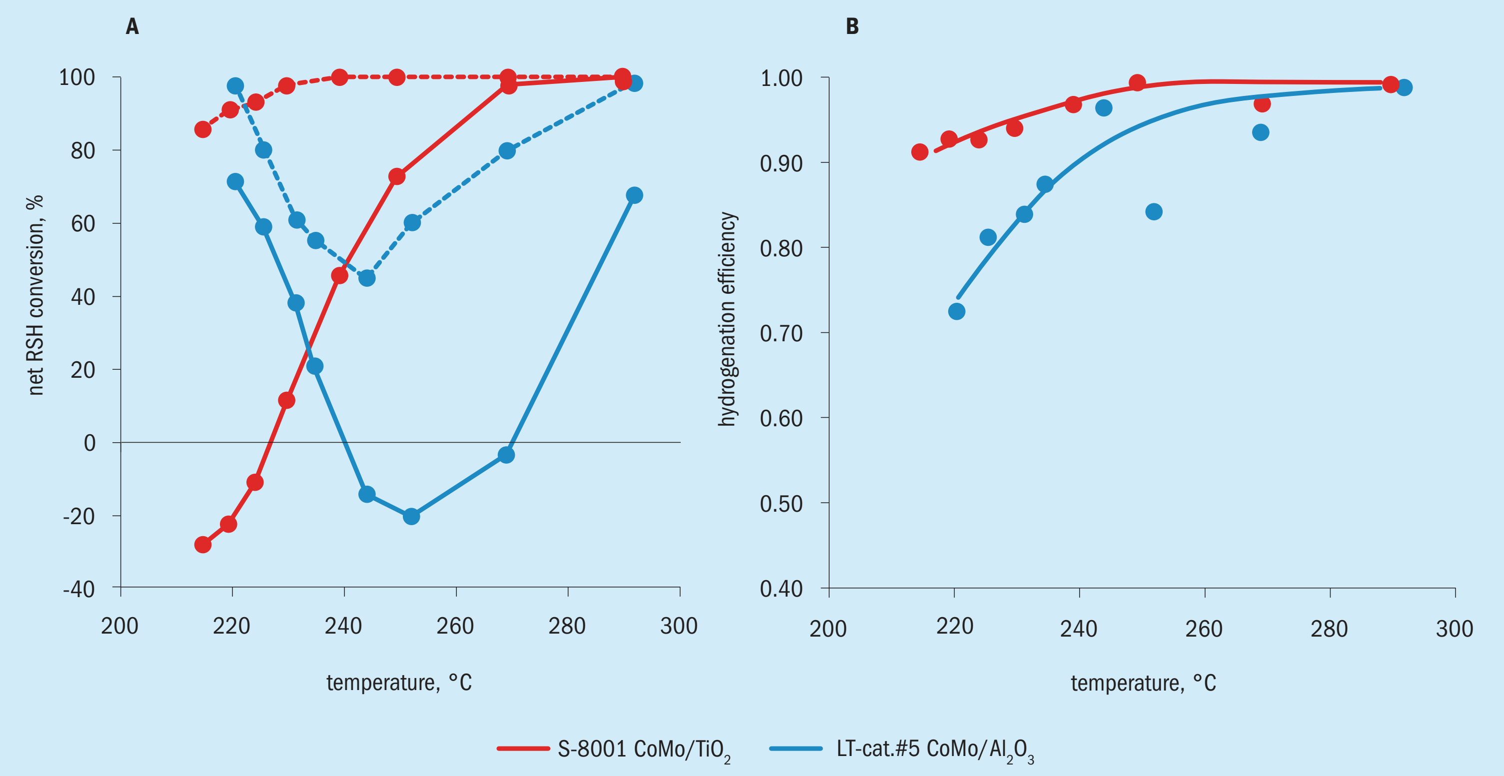
$$CH_3SH(g) + SO_2(g) \rightarrow CS_2(g) + 2\,H_2O(g) \quad (9)$$

This reaction can take place when the rate of $CS_2$ hydrolysis is too low and the hydrogenation pathway becomes kinetically favoured. Apart from a loss of sulphur recovery, methyl-mercaptan formation constitutes a loss of $H_2$ from the feed through its oxidation by $SO_2$ (and $S_x$) back to $CS_2$ and water (equation 9).

Fig. 5 clearly illustrates that the intrinsic higher activity of the titania support for the hydrolysis reactions offers an obvious advantage over alumina in terms of mercaptan formation at low temperature. The reason why the classical TGTU catalyst S-4001 exhibits a lower rate of mercaptan formation than expected can be found in the overall loss of hydrogenation activity of the catalyst at temperatures below 250°C, which is outside the operation window.

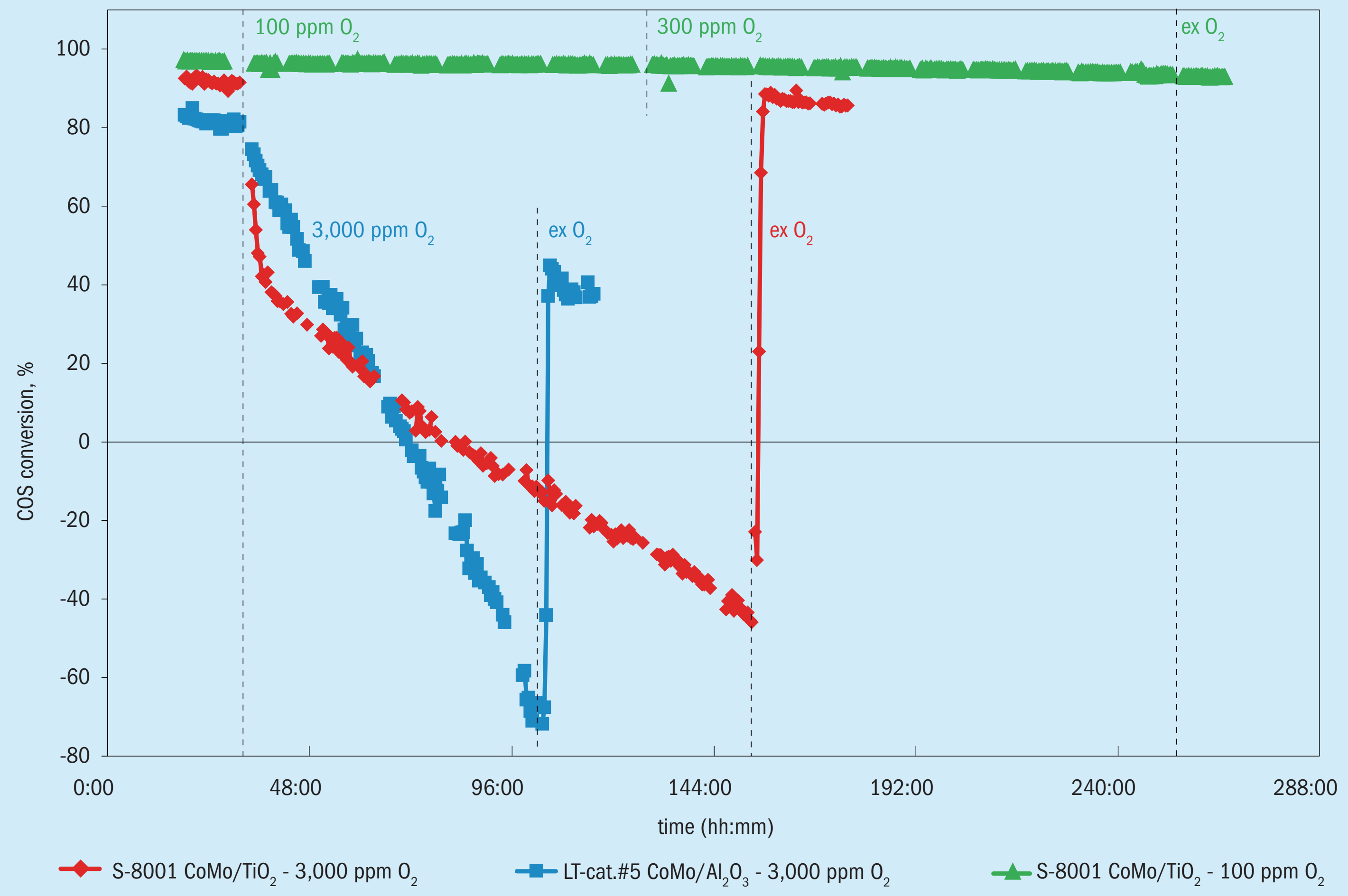
Mercaptans that are present in the feed are in principle converted in the catalytic converters of the Claus plant. However they still might occur in the feed of the TGTU in case some stream from outside the Claus plant is added. Fig. 6 shows what happens when methyl- and ethyl-mercaptan are present in the feed to the TGTU hydrogenation reactor. Both mercaptans can be converted through oxidation by $SO_2$ and $S_8$, however it must be noted that these conversion reactions are significantly slowed down when more $H_2$ is present in the feed than the stoichiometric amount required to convert all $SO_2$ and elemental sulphur to $H_2S$ (data not shown for brevity). A surplus of hydrogen, as is always the case in practical situations, will cause a quick drop in the $SO_2$ and $S_x$ concentration in the catalyst bed and hence significantly interfere with the mercaptan conversion reactions. From the graph in Fig. 6A it was concluded that ethyl-mercaptan is more readily converted than methyl-mercaptan. To effectively convert methyl-mercaptan somewhat higher catalyst temperatures above 250°C were required for the titania supported catalyst, while the alumina supported low temperature catalyst requires an catalyst bed temperature above 290°C to significantly reduce the mercaptan concentration. From Fig. 6A it seems that the alumina-based catalyst is more effective in converting mercaptans at low temperatures <240°C. It must be noted thought that the overall hydrogenation efficiency, defined as the fraction of sulphur species in the feed that is converted to $H_2S$ drops significantly at decreasing temperature as is illustrated in Fig. 6B. At these low temperatures the alumina-based catalyst converts mercaptan into $CS_2$ which cause a large net production of $CS_2$ and COS and a loss off hydrogenation efficiency in the catalyst bed. This effect is most pronounced for the alumina based catalyst.

Fig 6: **(A) Methyl-mercaptan (solid line) and ethyl-merceptan (dashed line) conversion in a typical TGTU feed over titania and alumina supported low temperature TGTU hydrogenation catalysts. (B) Hydrogenation efficiency of the different low temperature catalysts defined as the fraction of sulphur components in the feed that are converted to $H_2S$**




*The feed gas contained 250 ppm (wet basis) of both mercaptans.*
*Hydrogen concentration in the feed was 2.2 x the stoichiometric amount required to hydrogenate all $SO_2$ and Sx.*

Fig 7: **COS conversion versus time on stream over commercial titania and alumina supported low temperature TGTU hydrogenation catalysts in 3,000 ppm and 300 ppm $O_2$**




*All catalysts were loaded fresh into the reactor and pre-activated under optimal conditions. Gas inlet temperature for all experiments was 230°C.*

Although the exact temperatures required to convert mercaptan in the feed effectively will depend on the exact feed gas composition and will therefor differ for different plants, it is clear that the titania supported TGTU catalyst offers a large advantage in removing these difficult components from the gas stream.

## Oxygen resistance

Whichever TGTU catalyst is employed in the hydrogenation reactor, all catalysts are extremely sensitive to oxygen ingress. In TGTU installations where an in-line burner is installed for reheating the tail gas, this creates an additional operational challenge. The burner has to operate substoichiometrically, however care has to be taken not to operate the burner in too lean oxygen to prevent soot formation. Unfortunately, both soot and oxygen have a detrimental effect on the catalyst performance.

Euro Support investigated the sensitivity of the sulphided CoMo TGTU catalysts to $O_2$ ingress in long term stability tests. The results are shown in Fig. 7.

Prior to testing, all three catalysts were activated at optimal conditions at high temperature and stabilised at 230°C in process gas in order to have a clear baseline for the performance of each catalyst. At 35 h on stream 0.3 mol-% $O_2$ was introduced in the feed gas to simulate a serious mishap in the plant where a significant amount of $O_2$ slips into the reactor.

Both the S-8001 catalyst and its low temperature alumina based counterpart respond heavily to the $O_2$ ingress and lose activity instantly, indicated by the quick drop in COS conversion. Due to the oxidation reactions taking place over the catalysts virtually all $O_2$ is converted and the maximum bed temperature increases from ~240°C to ~270°C for both catalysts. For both materials the deactivation is progressive and after roughly 75 h on stream the COS conversion turns into a net COS formation. Remarkably, while the initial deactivation of the titania based catalyst is rather dramatic, the subsequent deep deactivation rate is much slower. The alumina catalyst on the other hand loses activity linearly over time and eventually becomes deactivated more severely than the titania based catalyst.

When either of the catalysts reached a significant level of COS production, the $O_2$ in the feed gas was again brought to zero to see how the catalysts would recover from this event and what permanent damage was done. When removing the $O_2$ from the feed gas, the COS conversion is immediately partly restored for both catalysts. After more than 100 h operation in 3,000 ppm $O_2$ in the feed gas, the COS conversion activity of the S-8001 is restored to 94% of the original activity. The alumina based low temperature catalyst has lost 53% of its activity.

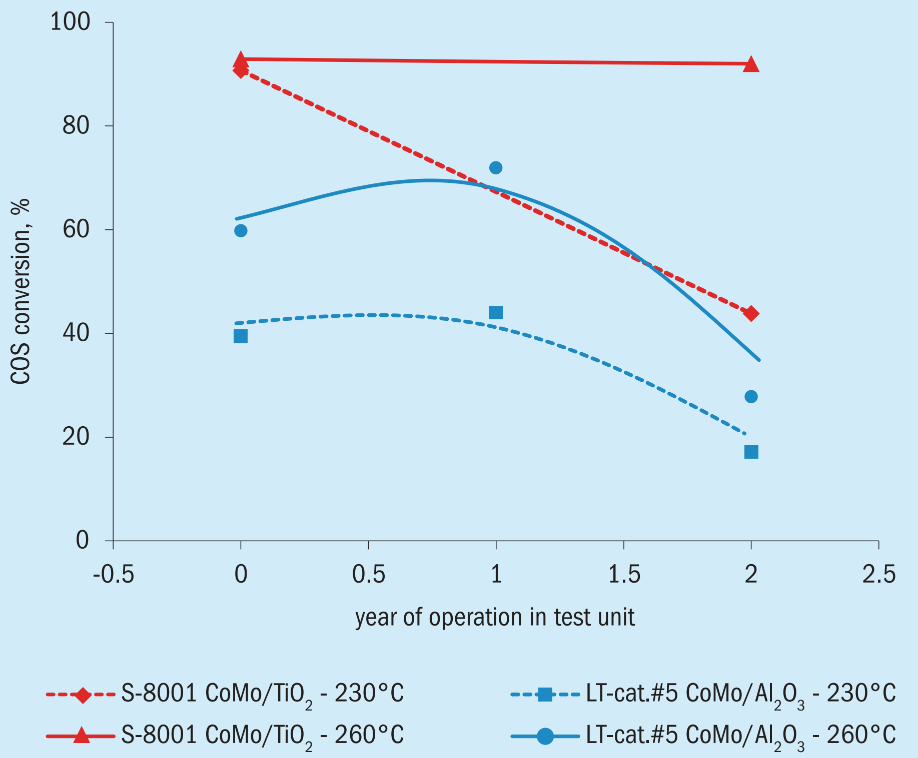
This largely improved ability to restore catalyst activity after $O_2$ ingress into the catalyst bed is related to the ease at which the titania supported CoMo catalyst is sulphided. This has been shown this for the start-up of fresh catalyst in the previous section, and the same principles of the easy sulphidation play a role here. It must be noted that after the partial deactivation by $O_2$ ingress it is not easy in practice to restore the catalyst by performing the start-up sulphidation procedure again. As the major part of the catalyst is still in its sulphided form it is not possible to generate sufficient heat from the process to improve the sulphidation degree, as is the case when starting a fresh catalyst that is in its oxide state.

To investigate the resistance of the S-8001 to continuous ingress of low ppm levels, of $O_2$ the experiment was repeated at a 30x and 10x lower $O_2$ concentration (Fig. 7, green symbols). After activation of and stabilisation of a fresh catalyst sample, 100 ppm $O_2$ was introduced into the feed. Over the course of 90 hours, no decrease in COS conversion could be observed. After 130h on stream the $O_2$ feed concentration was increased to 300 ppm. Over the next 120 h a marginal drop in COS conversion from 95.6% to 93.2% could be observed. After switching off the $O_2$ at 250 h on stream no increase in COS conversion was observed. Whether the apparent drop in activity is an effect of the stability of the experimental setup or an irreversible loss in activity therefore remains inconclusive. Nevertheless, based on the presented results it can be concluded that in cases where oxygen enters the hydrogenation reactor, even at temperatures as low as 230°C the rate of the sulphiding reactions in principle can keep up with the rate of the oxidation reactions when the $O_2$ concentration is sufficiently low, i.e. <100 ppm. This stability could be a significant advantage in units that have problems with $O_2$ ingress into the hydrogenation reactor.

## Catalyst lifetime

Both the S-8001 and the reference alumina based low temperature TGTU catalysts were tested over the course of two years in the Euro Support test labs under many conditions that are detrimental to the catalyst activity (including high $SO_2$ concentration, low $H_2$ concentration, the presence of mercaptans, BTX etc.). In between the different sets of conditions, the catalysts were regularly resulphided at high temperature, to ensure optimal catalytic performance. After two years of continuous testing the standard activity test was performed to get some insight in the degeneration of the catalyst over time. Again COS hydrolysis activity was taken as a measure for the overall state of the catalyst.

**Fig 8: Activity of low temperature TGTU catalysts**




*Evolution of the activity of the low temperature TGTU catalysts comparing start of run performance with the COS conversion activity at a bed temperature of 230°C and 260°C after 1 year and 2 years of operation in the test unit at diverse conditions and many de-activation and re-activation treatments. The test unit was completely overhauled between SOR and year 1 of the test program of LT-cat.#5. Performance data of the S-8001 catalyst after 1 year of testing is not available.*

The COS hydrolysis activity at a bed temperature of 230°C at start of run (SOR) and over time are presented in Fig. 8. Although there is a remarkable increase in activity observed for the alumina based LT-cat.#5 after the first year of testing the general trend is downwards, as expected. The apparent increase in activity is most probably an artefact originating from the large overhaul of the test unit between SOR and year 1 of this research program. Although after two years, both catalysts have lost significant activity for the COS hydrolysis at 230°C, the loss in activity of the S-8001 at 260°C is negligible (<1%) while the alumina based low temperature catalyst has lost approximately 50% of is hydrolysis activity.

## Conclusions

Based on the test results it was concluded that in all addressed circumstances the S-8001 not only offers performance benefits that will boost the efficiency of the TGTU, but also deals more adequately with difficult to remove species as mercaptans, offers an easier start-up, exhibits higher oxygen resistance and a very efficient re-activation in case of a mishap, as well as a longer lifetime at low temperature. ■

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