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SULPHUR
ISSUE 375
MARCH-APRIL 2018

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Cover: *The Capital Gate Tower, Abu Dhabi stands at 160 m tall and leans at an astounding 18 degrees to the west. Alan64/iStockphoto.com*

North African phosphates

A major source of sulphur demand over the coming years.

Sulphuric acid plant simulation

Improving efficiency through modelling.

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Reality begins to dawn

We are now less than two years from the time when all ships must be either running on fuel with a sulphur content of less than 0.5%, or else have remedial measures in place to scrub their engine exhausts, and it feels as if the cold, hard reality is finally beginning to dawn upon the shipping and other industries – this is going to be chaotic, and potentially quite expensive.

Perhaps one of the biggest surprises in the run-up to the January 1st 2020 deadline (the IMO had the option of delaying this to 2025, but has decided against it) is the lack of penetration of exhaust scrubbing technologies. So far, less than 1% of cargo vessels covered by the legislation (about 400 out of 60,000 ships) have so far installed scrubbers or placed firm orders to do so. Some of this comes down to concerns over corrosion, and uncertainty over the cheapest form of scrubbers – open loop wet scrubbers, which discharge acidified waste directly into the sea – and whether there is likely to be a future crackdown on this. But, as evidenced by a recent report by shipping line Pacific Basin, most ship owners simply do not believe that they are practical or cost effective. Maersk has already said that it will not use scrubbers for Annex VI compliance, and Shell believes that by 2020 only 1,500 ships (2.5% of cargo vessels) will have been converted to run on scrubbers.

> **This is going to be chaotic, and potentially quite expensive.**

Likewise penetration of alternative fuels has so far been relatively small. Less than 0.5% of ships have been designed or converted to operate on LNG, methanol or other, and take-up by 2020 is unlikely to be more than 1%. The upshot is that this will leave 96.5% of ships that fall under the legislation having to rely on purchasing marine gasoil or other low sulphur refined fuels come January 2020, and the ability of the refining industry to supply sufficient fuels is very much in doubt.

There has been a slightly blithe assumption from the shipping industry that the rule may simply prove to be unenforceable, and that in many cases it might be preferable to try and front it out – continue using high sulphur fuel oil and gamble on not being caught or prosecuted, and where that happens, simply accept whatever fines are handed down. Perhaps large-scale non-compliance might even force the IMO into a re-think about not extending the deadline to 2025, the thinking goes. The IMO is after all a United Nations organisation and has no enforcement capability. Likewise port states are not authorised to police the rule – only flag states – the country which licenses a ship to operate – are currently allowed to enforce the standard. However, the IMO is fully aware of this and its members seem to be taking a firm stance. It has charged its Pollution Prevention and Response (PPR) sub-committee with taking the lead role on the enforcement issue, and in a recent meeting PPR identified four main mechanisms for tightening enforcement, chief among which is authorising port states to enforce compliance. A new report by insurance broker Marsh: *Emissions Regulations: Concerns for the Marine Industry*, points out to ship owners that ships that are found out of compliance potentially face losing seaworthiness certificates, flag state convention certification, and possibly even insurance cover. Other levers include garnering support from large receivers of shipped goods to use only vessels that comply with the regulations to avoid negative consumer sentiment, or even prohibiting vessels without onboard scrubbers from transporting fuel oil with a sulphur content greater than 0.5%. The only get-out looks likely to be a so-called FONAR – Fuel Oil Non-Availability Report – specifying that low sulphur fuel was not available at the port when the ship fuelled. The shipping industry is somewhat belatedly starting to realise that 2020 could be a very difficult year indeed.

It is likely too late even for a last minute rush for scrubbers or alternate fuel engines to make much of a difference. Now the question is whether refiners will invest in desulphurisation capability in advance of the deadline, in anticipation of being able to take advantage of a spike in low sulphur fuel demand, or whether they wait and see how things shake out. Either way, there are significant costs ahead for someone, whether it is the ship owner, the refiner or the consumer, and probably all three.

Richard Hands, Editor

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Price trends

MARKET INSIGHT

Oliver Hatfield, Director, Fertilizer Research Team, Integer Research (in partnership with ICIS) assesses price trends and the market outlook for sulphur.

SULPHUR

Compared to the frantic activity seen during the last few months of 2017, the first two months of 2018 felt a bit like the calm after the storm. After falling during the first week of January 2018, the spot price of solid sulphur delivered to China was flat during the rest of January and February at around $135-140/t c.fr. Similarly, the spot f.o.b. Vancouver reference flatlined at around $125/t f.o.b. during February having lost around $30/t during the first three weeks of the year. The drop in prices was to be expected given how rapidly prices had increased at the end of 2017. The delivered China reference topped out at around $220/t, the highest level since February 2014.

Recent prices are still substantially higher than levels seen during the majority of 2017, and the subsequent correction has seen values level off to those seen in September 2017, when the rally in prices really accelerated. For most of the first three quarters of 2017, the average Vancouver f.o.b. spot price was in a $75-100/t range. February 2018 prices are still around a third higher than in February 2017, when the month average was around $90/t.

China was a main focus of the spike in prices in 2017. The drop in Chinese port stocks to around 1.0 million tonnes was an important feature of the price rally, but stocks have since recovered substantially and in February 2018 reached around 1.4 million tonnes. We now have the benefit of hindsight to consider the nominal amount of Chinese imports during the rally. It is interesting that imports in each of the last three months of the year amounted to 0.8-0.9 million tonnes, around 100,000 tonnes per month less than the previous quarter. For the last quarter of 2018, China imported around 0.5 million tonnes less than in Q3 2017. This illustrates that the tight market could not be explained solely by increased Chinese imports.

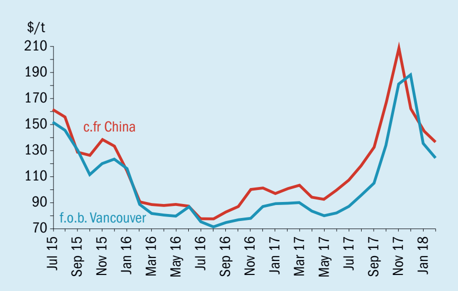
Supply limitations were a contributing factor. Availability of exports from the Middle East were reduced by the start-up of the Ma'aden phosphate project in Saudi Arabia which increased domestic sulphur demand in the second half of 2017. We can now see that H2 2017 Saudi Shipments to the US were lower by around 200,000 tonnes compared to the first half of the year. Export shipments from Iran were also notably lower in the last quarter of 2017, compared to the rest of the year.

Changes in the phosphates sector were also an important demand side contribution. OCP of Morocco which is extending its position as the world's leading phosphates producer by making substantial investments in expansion and downstream processing greatly increased its international sulphur activity through 2017. OCP depends on the international sulphur market, and to a lesser extent the sulphuric acid market, for its raw material to upgrade phosphate rock to intermediate and finished products. Increased investment in this processing capacity meant the company increased its sulphur imports to more than 3 million tonnes in the second half of the 2017, compared to around 2.4 million tonnes in the first half. It's likely that Q4 imports would have been higher but OCP was frustrated after the cancellation of its contract shipments for that period from Russia due to weather-related logistics disruption. Consequently, North African sulphur prices moved up with other spot sulphur prices, though for quarter contract shipments there was a substantial lag behind spot levels.

There remains significant uncertainty in the sulphur market concerning the near term direction of prices because the market remains finely balanced. Recent monthly price announcements for March illustrate this. Prices had been falling, but Saudi Aramco announced it was increasing prices by $15/t to $135/t. Muntajat announced a similar increase to $134/t. On the other hand, Adnoc announced it March Official Selling Price (OSP) to the India market at $140/t, a rollover from February. Optimism about prices is founded on the expectation that demand from China will be relatively strong, once buying normalises after the Lunar New Year holiday period.

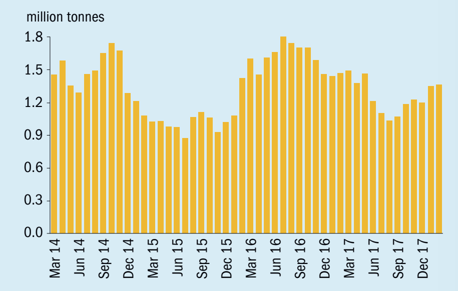
There is a risk that it sounds like a stuck record, but we must repeat that the timing of various project start-ups remains the main point to watch for price direction in 2018. The Kashagan project in Kazakhstan is still in the limelight, not surprisingly given its potential to substantially add to the sulphur supply balance. The project so far has had no impact on the international sulphur market, with sulphur movements understood to be slow, but the prospect is getting closer. Oil and gas production volumes are increasing, with current oil production reported at 300,000 barrels per day, compared to a target output level for the year of 370,000 barrels per day which is expected to be reached by the middle of 2018. In China there are a handful of projects which are expected to boost the country's sulphur output by around 1 million tonnes, which is likely to be sufficient to reduce Chinese demand for sulphur imports. Once these projects are up and running they will lead to increased export availability and reduced import demand, and weaker sulphur prices will follow.

Fig. 1: **Month average spot sulphur prices, Jul 15 to Feb 18**



Source: Integer, ICIS

Fig. 2: **China sulphur port inventory, Mar 2014 to Feb 2018**



Source: Integer, GTIS

SULPHURIC ACID

The start of 2018 has seen sulphuric acid prices rising in most markets. With the odd relatively short-term correction or flat spell, prices have increased almost uninterrupted since the first half of 2016. The NW European spot acid price reached $40/t in the second half of February 2018, almost double the level seen in November 2017. There are some reports that spot European cargoes have moved to 5 year highs of around $50/t. It's worth reflecting that for a short period in May 2016, spot prices at the NW European reference were negative.

For sellers in Japan and Korea, spot sulphuric acid prices have been relatively flat during the first two months of the year at around $25/t, which is about $10/t lower than the peak 2017 level, seen in September and October, but February 2018 prices are still above the 2017 annual average. Japanese and South Korean sellers were selling at negative netbacks as recently as January 2017, and the recent low point saw negative values dip to negative $22/t in May 2016.

Market sentiment continues to be tight in 2018. In Europe spot availability for the first half of 2018 is reported to be tight. Likewise, the substantial loss of acid supply volumes in East Asia at end of 2017, due to maintenance at smelter producers, is still having a significant effect on export availability this year. Producers are consistently reported to be short on spot supply for the whole of the first half of 2018. Not surprisingly in that environment, contract negotiations and agreements are showing price inflation. Some Asian contract agreements for Q1 2018 were agreed at $30/t, up $10/t.

Supply disruptions continue to impact the market balance. The PASAR operation in the Philippines which can produce around 50,000 tonnes per month, declared force majeure due to a typhoon. Industrial action in Chile reduced domestic supply at the end of 2018, contributing to a tight market, leaving buyers scrambling for import cargoes. With relatively buoyant copper prices, budgets for acid procurement were sufficient that shipments of virgin acid from China were agreed, with three 20,000 tonne cargoes reported to have been settled in December at $40/t f.o.b. China. These shipments illustrated that although spot sulphur prices were significantly weaker than their November highs, they were still sufficiently inflated to support buoyant sulphuric acid prices.

While some metals buyers could afford higher acid prices, other buyers were feeling the pinch from acid price inflation. In Brazil, some phosphate buyers were put off sufficiently to scrap tenders. In India, negotiations over 2018 contracts became protracted, with buyers offering East Asian suppliers $30-40/t c.fr, while sellers were $10/t higher. A compromise was reportedly agreed on some deals by linking acid prices to a third of the delivered India sulphur price, less a % discount. Short of regular sulphur supplies in Q4 2017, OCP of Morocco was still active in the acid market in the first two months of 2018. Trade data shows that OCP imported 1.6 million tonnes of acid in 2017, up by around 160,000 tonnes on 2016, and around 670,000 tonnes than in 2015.

The sulphuric acid market is expected to be tight during the first quarter at least and likely Q2 as well. It's not entirely clear yet whether the market balance is such that prices will just hold on to their recent gains or whether we see further inflation; it seems unlikely that prices will weaken in that timeframe.

Price indications

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

Cash equivalent	September	October	November	December	January
Sulphur, bulk ($/t)					
Vancouver f.o.b. spot	103	170	175	145	120
Adnoc monthly contract	110	127	184	195	140
China c.fr. spot	135	185	190	150	135
Liquid sulphur ($/t)					
Tampa f.o.b. contract	74	74	110	110	116
NW Europe c.fr.	117	117	123	123	136
Sulphuric acid ($/t)					
US Gulf spot	50	60	60	60	65

Source: various

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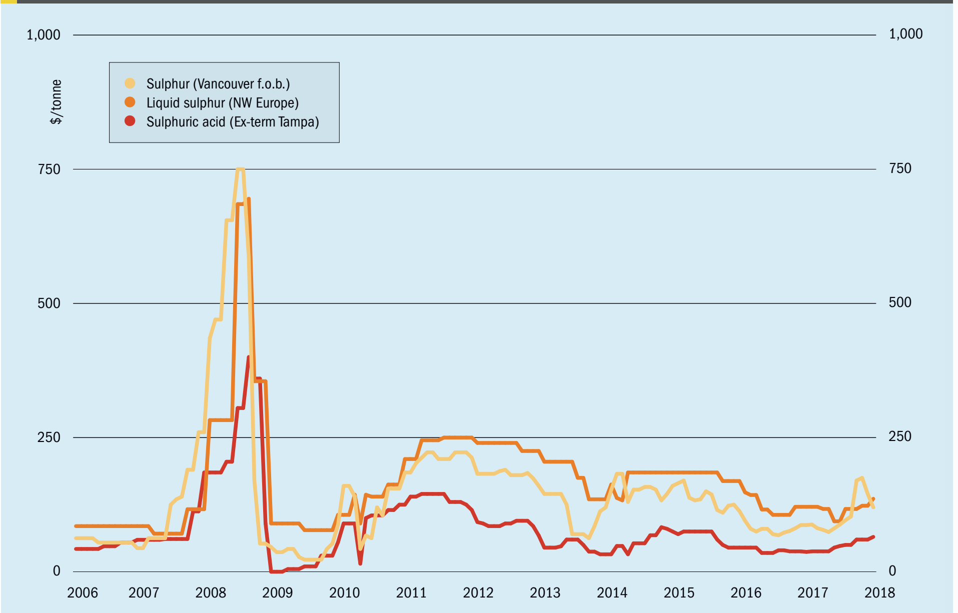
Market outlook

Historical price trends $/tonne



Source: BCInsight

SULPHUR

- The timing of the start-up of key sulphur producing projects remains the key variable on the supply side. Kashagan can potentially produce 1.1 million t/a of sulphur at full capacity. According to the North Caspian Operating Company (NCOC), 143,000 tonnes of sulphur have been exported by rail in the past three months. Oil production is currently said to be running at 80% of capacity.
- Additional sulphur production from various projects in China may total up to 1 million t/a, which may impact upon Chinese demand for sulphur imports, although there is no sign of this at present, and expectations of increased Chinese buying are continuing to support the market.
- In the meantime, Chinese port stocks have recovered considerably from their low point towards the end of last year, and have now reached 1.4 million tonnes, easing pressure for more imports and bringing sulphur prices back down to a more natural level, but still around 30% up on the same time in 2017. Increased demand from Ma'aden phosphates in Saudi Arabia has served to reduce export availability from the Gulf, and continuing expansions at OCP in Morocco have also had an effect on tightening the market overall.

SULPHURIC ACID

- Prices have risen in most markets at the start of 2018, and sulphuric acid markets are expected to continue to be tight during 1Q and possibly through 2Q 2018. The main challenge for the sulphuric acid outlook is predicting availability on the supply side. It remains to be seen how quickly markets adjust to normal output from recently restarted plants in North America for example, although there are also several new consuming projects either ramping up or scheduled to come on line in North America.
- Elsewhere, there is further scheduled maintenance but more importantly unplanned downtime. Important sources of export acid in Asia have lower availability. In South Korea, Korea Zinc is taking 43-45 days of maintenance downtime reducing production by around 50,000 tonnes, while LS-Nikko Copper is also taking a 3 week turnaround. It is not clear when the PASAR operation in the Philippines will resume normal exports.
- There is likely to be relatively close connection between the markets for acid and sulphur. In our market balance projections, export supply from China will be required to close a supply gap. These cargoes are only viable if producers like Two Lions see the arbitrage opportunity between sulphur raw material costs and acid prices.
- Unless sulphur prices drop, there is no room for sulphuric acid prices to decline, and further inflation may be necessary. In addition, buyers like OCP which have a degree of substitutability between making and buying acid will lean toward the acid market if its regular sulphur supplies remain constrained.

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Sulphur Industry News

ABU DHABI

Adnoc to invest $3.1billion in upgrading Ruwais refinery

The Abu Dhabi National Oil Company (Adnoc) has announced its plan to invest $3.1billion to upgrade its Ruwais oil refinery in the west of the Emirate. The refinery upgrade project, known as the Crude Flexibility Project (CFP), is intended to introduce crude processing flexibility and free up more Murban grade crude. The project is looking to completion in late 2022, allowing the Ruwais Refinery West complex to process up to 420,000 bbl/d day of Upper Zakum crude (1.33% sulphur) or similar grades. Adnoc says that the project is part of its downstream refining strategy, intended to boost margins by introducing asset flexibility and product marketing initiatives.

The upgrade project will involve installation of an atmospheric residue de-sulphurisation (ARDS) unit which designed for upgrading medium to heavy petroleum oils and residues to environmentally friendly transportation fuels. It is also used to partially convert the residues to produce low-sulphur fuel oil and hydro-treated feedstocks. Adnoc has awarded the engineering, procurement and construction (EPC) contract to a joint venture between South Korea's Samsung Engineering and Netherlands' CB&I. ■

New gas sales agreement with Dubai

Adnoc has also signed a 15-year gas sales agreement with the Dubai Supply Authority for the supply of natural gas to help meet Dubai's energy needs. The agreement was signed at Adnoc's headquarters by Sheikh Ahmed bin Saeed Al Maktoum, Director General of the Dubai Supply Authority, and Sultan Ahmed Al Jaber, UAE Minister of State and Adnoc Group CEO.

As part of its 2030 growth strategy, Adnoc plans to access undeveloped tight reservoirs, tap into its gas caps and expand sour gas production, ensuring that it delivers a sustainable and economic gas supply to meet the UAE's growing demand for energy. In addition, it has commenced an exploration drilling programme to explore for, and appraise, the potential of individual gas deposits in tight reservoirs. The Emirate is committed to spending $109 billion over the next five years, and recently awarded FEED contracts for the Hail, Gasha and Dalma sour gas fields to Bechtel and Technip (see *Sulphur* 274, Jan/Feb 2018, p11), which are expected to produce 1 billion cfd of sales gas.

China, Germany seeking to partner sour gas developments

Sultan Al Jaber, UAE Minister of State and Adnoc Group CEO, met with government and corporate leaders in Beijing, to explore opportunities for strengthening the strategic relationship between the UAE and China and deepening the partnerships between Adnoc and China's energy, chemical and technology sector. China is the UAE's largest trading partner, with bilateral trade topping $50bn per year. In the past year, China and the UAE have made a number of joint venture investments in the energy sector. In February 2017, the CNPC and China CEFC Energy were awarded minority stakes in the UAE's onshore oil reserves, and in November 2017, Adnoc and CNPC signed a framework agreement covering various areas of potential collaboration, including offshore opportunities and sour gas development projects. Adnoc is focused on market expansion in China and Asia, where demand for petrochemicals and plastics is forecast to double by 2040.

Meanwhile, BASF subsidiary Wintershall, Germany's largest oil and gas producer, has told Abu Dhabi English language newspaper *The National* that is looking to partnerships in sour gas development in Abu Dhabi as it seeks to increase its Middle East footprint. The firm has tested two wells in the western sour gas field of Shuwaihat, near Ruwais, in partnership with Adnoc and Austria's OMV, and says that it is now "looking to play a larger role".

AZERBAIJAN

Tecnimont awarded refinery revamp contract

Maire Tecnimont says that its subsidiaries Tecnimont SpA and KT-Kinetics Technology have been awarded the engineering procurement and construction (EPC) contract for the modernisation and reconstruction of Heydar Aliyev Baku oil refinery in Azerbaijan. The contract was awarded by the State Oil Company of Azerbaijan Republic (SOCAR), and is worth $800 million. The project scope covers the installation of several new grassroots process units, relevant utilities and storage, with the final aim of upgrading the refinery to be capable of processing 7.5 million t/a of crude oil, while meeting the quality requirements of both feed for Azerikimya's revamped petrochemical plant and to produce Euro V quality automotive transportation fuels.

New process units include a naphtha splitter, a diesel hydrotreater unit, an isomerisation unit, a hydrogen production unit, two PSA units, a C4 hydrogenation unit, an MTBE unit, and a sour water stripper unit with sulphur recovery unit. The project is expected to be completed 41 months from the signing date.

Pierroberto Folgiero, Maire Tecnimont chief executive officer, commented: "after our two strategic petrochemicals projects in Azerbaijan, this contract enables Maire Tecnimont Group to consolidate relations with SOCAR in the refining business, supporting their strategy of integration with the petrochemical business."

IRAN

Qeshm Island facilities in pre-commissioning

Hamid Bovard, the managing director of Iranian Offshore Oil Company, says that new gas processing facilities for the Hengam oil and gas field on Qeshm Island in the Gulf are in pre-commissioning and due to come on stream in the near future. About $87 million has been spent on the facilities, which will prevent the flaring of 2 million m³/d of associated gas. Bovard said that following the completion of installation operations in December 2017, pre-commissioning and commissioning stages have begun, and over the past two months all processing, infrastructure and utility units, including dehumidification, sweetening, pipeline, tanks, boilers and compressors, have come on stream under the pre-startup safety review. The facility will double gas production at Qeshm, which also takes gas from the Gavarzin gas field. Iran has struggled for some years to curb the flaring of large amounts of associated gas, and at the beginning of last year, Iran's parliament passed a bill to curb the flaring of natural gas to 10% or lower of its value by 2021.

Drilling platform at South Pars.

Iran also says that the first offshore drilling platform in South Pars Phase 14 has been successfully installed in the Gulf, with the capacity to extract 500 million cfd of natural gas. As soon as pipeline tie-ins are complete, sour gas from Phase 14 will be transferred to South Pars 2 processing facilities before being injected into the Iran Gas Trunkline. Eleven wells have been drilled around Platform 14A, of which eight will go on stream by the end of February, according to the National Iranian Oil Company. Satellite platforms (14C and D) will be connected to the two main platforms (A and B) by 18" pipelines. Platform 14B is said to be "88% complete". South Pars Phase 14 is scheduled to produce 56 million cubic meters of gas and 75,000 barrels of gas condensates per year to meet domestic gas demand and supply feedstock to petrochemical units in the Pars Special Energy Economic Zone in the southern Bushehr Province. The phase is also expected to annually produce more than 1 million tons of gas condensates, 1 million tons of ethane for petrochemical units and 400 tonnes of sulphur.

The project is under development by a consortium consisting of Industrial Projects Management of Iran, Industrial Development & Renovation Organization of Iran, Iranian Offshore Engineering and Construction Co., Iran Shipbuilding & Offshore Industries Complex Co., MAPNA Group, National Iranian Drilling Co., and Machin Sazi Arak. The gas sweetening facility that forms part of South Pars 13 is also ready to begin operations, taking gas from South Pars 6, 7 and 8.

Ilam SRU to be completed soon

Ilam refinery's new sulphur recovery unit will be inaugurated next spring, according to managing director of the National Iranian Petrochemical Company Seyed Reza Norouz-zadeh. During a visit to the Ilam Petrochemical Complex, Norouz-zadeh told local media that the SRU has made good progress in the last two years. He said that the refinery's revamp will be completed by the end of the current Iranian year [ending March 2018] and the site will be fully operational in the first quarter of the next Iranian year [2Q 2018]. In addition to the SRU, the managing director of Persian Gulf Holding Adel Nejad Salim also added that 89% of other work at the Ilam Petrochemical Complex has been completed. The new project will have the capacity to produce 450,000 t/a of ethylene, and is also expected to become operational early next Iranian year. He noted that more than 80% the refinery's petrochemical products will be marketed internationally.

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KAZAKHSTAN

Contract awarded for TCO acid gas reinjection project

Bonatti has been awarded the Area 51 Pipelines contract by Tengizchevroil (TCO) for the Future Growth Project/Wellhead Pressure Management Project (FGP-WPMP), which will create a new gathering system for transporting gas from the Tengiz and Korolev reservoirs to the new processing facilities. Scope of work includes the construction and pre-commissioning of 377 km of pipelines, including the production gathering system and high pressure sour gas injection and associated utilities. They will be partnered by local firm Montazhspetsstroy JSC.

Elsewhere in Kazakhstan, the giant Kashagan field has resumed production after power disruptions at an onshore facility cut output in mid-January. Production from Kashagan helped drive the country's crude exports higher during 2017. By the end of the year Kashagan's production was running at 250,000 bbl/d, and it is anticipated that it will reach its first phase capacity of 370,000 bbl/d during 2018. The ramp-up at the field has also been responsible for Kazakhstan over-producing its agreed OPSC quota.

NCOC says that Kashagan has exported 140,000 tonnes of sulphur

In mid-February, the North Caspian Operating Company (NCOC) announced that it had exported 143,000 tonnes of sulphur from Kashagan since the first train left from the Eskene West three months previously. The company says that over that period a total of 37 trains loaded with sulphur have been exported – three each week, each with a total of 60 rail cars. The trains travel to the export terminal at Ust-Luga near St Petersburg as well as Port Kavkaz in the Caucasus. The company also says that it has formed a total of 191,000 tonnes of sulphur granules since production began at the gas processing site. At capacity, the Kashagan sour oil and gas project will be producing 4,500 t/d of sulphur, or 1.1 million t/a. Some liquid sulphur has been poured to block, but once design capacity is reached the full amount will be formed and exported, according to NCOC, and the company is also planning to melt and process into granules the sulphur accumulated in the sulphur blocks.

PHOTO: AZERNEWS

One of the artificial island production platforms, Kashagan.

UKRAINE

Honeywell to provide hydrotreating catalysts for Shebelinsky refinery

Honeywell says that UkrGasVydobuvannya (UGV) has begun using Honeywell UOP's *HYT-4118 Unity* hydrotreating catalyst to produce ultra-low sulphur diesel fuel at the Shebelinsky refinery in Andreyevka, in eastern Ukraine's Kharkov region. The catalyst removes sulphur from petroleum feeds that are used to make distillate, and is designed for use in low- to medium-pressure ultra-low sulphur diesel (ULSD) hydrotreating units, providing high activity and stability for longer cycle lengths with low hydrogen consumption and ensuring sulphur content of less than 10 ppm in the resulting fuel.

UkrGasVydobuvannya is the largest natural gas producer in Central and Eastern Europe accounting for 75% of natural gas production in Ukraine.

CHINA

CNOOC commissions DuPont wet scrubbing system

CNOOC recently commissioned a DuPont *BELCO® EDV®* wet scrubbing system at its oil refinery on Hainan Island, China. The system will allow the refinery to minimise atmospheric emissions of fine particulate and sulphur oxides (SOX) from its 1.2 million t/a fluid catalytic cracking unit (FCCU). The system was fitted by Beijing Milestone Technologies under license from DuPont Clean Technologies. MSTN and DuPont have licensed and supplied over 60 new BELCO EDV wet scrubbing systems for FCCUs in China, preventing over 200 000 t/a of air pollutants from SOx and fine particulate emissions to the atmosphere. DuPont says that the system controls particulate, SOx and NOx emissions in a single upflow tower, eliminating the need for separate control devices to manage different emissions.

INDIA

CPCL inaugurates refinery upgrade project

At the end of February, Dharmendra Pradhan, Minister of Petroleum and Natural Gas, inaugurated Chennai Petroleum Corporation Ltd's (CPCL) $480 million residue upgrade project at its Manali refinery near Chennai. CPCL, a subsidiary of the Indian Oil Corportion, has added a delayed coker with 2.2 million t/a of capacity, an 8.8 t/h LPG treatment unit and a sulphur recovery unit, as well as utilities and offsite facilities, in order to produce an extra 700,000 t/a of LPG and diesel, and up to 300,000 t/a of petroleum coke. The project will add value to the refinery, improving margins and profitability, as well as creating 130 jobs, said Pradhan. It will also allow the refinery to increase the percentage of high sulphur crude it uses as feed, reducing costs. Sulphur production at capacity will be 200 t/d (66,000 t/a).

Pradhan also said that CPCL will be implementing a 9 million t/a refinery expansion project at Nagapattinam at an investment cost of $4.15 billion.

DEMOCRATIC REPUBLIC OF CONGO

Outotec to supply acid plants for Mutoshi

Outotec has been awarded a €33 million contract by Shalina Resources Ltd for the delivery of sulphuric acid plant technology to the Mutoshi project near Kolwezi in the Democratic Republic of Congo. Outotec's scope includes the delivery of three skid mounted, modular sulphuric acid plants which will produce the acid and SO_2 gas required by the new Mutoshi copper-cobalt plant. The plant concept ensures the benefits of modular prefabricated plant delivery, such as low investment, installation and operation cost, increased availability and maintainability as well as environmentally sound and safe operation.

"We really look forward to working with Shalina Resources in the Mutoshi project, and are extremely pleased that we can complete our diverse technology package for the copper and cobalt processing now with sulphuric acid plants. These modular plants represent our latest technology, and remarkably improve the environmental performance of the plant", said Kalle Härkki, head of Outotec's Metals, Energy & Water business.

Glencore ups Katanga output estimate

Glencore says that it aims to increase cobalt output by 42% in 2018 compared to its figure for 2017 as production at the restarted Katanga facility ramps up to its capacity of 11,000 t/a, representing 28% of Glancore's total output for the year. Glencore completed the first stage of the ore leach processing at the facility in December, producing 2,200 tonnes of copper cathode by the end of the year. The site had been idle since September 2015, when production was halted because of oversupply of copper and cobalt on global markets. Cobalt production at Glencore's Mutanda facility in the DRC, dropped 3% in 2017 to 27,400 tonnes due to restrictions on sulphuric acid deliveries from the Mopani copper mine in neighbouring Zambia during 3Q 2017. Throughput restrictions at Mutanda resulting from heavy rainfall earlier in the year further contributed to the reduction in output.

ZIMBABWE

IDCZ to sell share in Chemplex

The state-owned Industrial Development Corporation of Zimbabwe (IDCZ) is seeking financial advisors to lead the part sale of its subsidiary Chemplex Corporation Ltd. The aim according to ICDZ is to "inject additional capital into the business, bringing in new technology and access to wider markets for the business." Chemplex is Zimbabwe's largest fertilizer and chemicals manufacturing company, and the parent company owns Dorowa Minerals and Zimbabwe Phosphate Industries Ltd (Zimphos), the country's sole producer of sulphuric acid, as well as aluminium sulphate and single superphosphate. It also owns 50% of Zimbabwe Fertiliser Company and 36% of Sable Chemicals.

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UNITED STATES

Itafos completes acquisition of Conda Phosphate Operations

Itafos says it has completed its acquisition of Conda Phosphate Operations from Agrium Inc., and the appointment of Ron Wilkinson to the board of directors of the company. The Conda Phosphate Operations, located in Conda, Idaho, includes phosphate production facilities and adjacent phosphate mineral rights, and produces approximately 540,000 t/a of mono-ammonium phosphate (MAP), super phosphoric acid, merchant grade phosphoric acid and specialty products for the North American fertilizer market. Agrium agreed to sell Conda for $100 million just prior to its merger with PotashCorp to form Nutrien in order to ease regulatory concerns and allow the merger to proceed. It also sold its North Bend Ohio nitric acid operations to Trammo Nitrogen Products Inc (formerly Transammonia).

Itafos says that Conda's new director Ron Wilkinson is a former Agrium executive with a career spanning 40 years in the fertilizer industry. He served as senior vice president and president of Agrium's Wholesale Business Unit from 2004 to 2015, responsible for manufacturing operations for 12 production sites, along with the associated supply chain, sales, marketing and distribution.

"Itafos continues to deliver on its strategic objective of becoming a leading global player in the phosphate fertilizer industry," said Brian Zatarain, chief executive officer of Itafos. "We are pleased to have closed this transformative transaction and look forward to working with Mr. Wilkinson who further strengthens the leadership of the company with extensive industry experience and a successful track record of driving profitable growth."

AUSTRALIA

Lithium Australia to pilot acid leach plant

Lithium Australia says that it has committed to building a large-scale pilot plant in order to commercialise its new SiLeach technology, following the results of a positive preliminary feasibility study in July 2017. SiLeach is a fluoride and sulphuric acid-based leach that is focused on optimising water balance and potassium sulphate production, eliminating the need for the usual lithium carbonate roasting process. Lithium Australia says that this reduces time, lowers operating costs and results in a more direct chain to battery-producing end users. The company says that it is aiming to have the pilot plant, reagent supplies, process feed material and supporting infrastructure in place by 2021, once agreements are finalised.

"Our commitment to advancing the SiLeach process to an industrial scale is a critical element in the research and development required to bring a superior process into the lithium industry," he explained.

CHINA

Start-up for world's largest WSA plant

The Bestgrand Chemical Group has announced the successful start-up of its wet gas sulphuric acid (WSA) plant in China. The plant will be the world's largest, with a production capacity of 300,000 tonnes of sulphuric acid per year. The plant will treat 131,000 t/a of acid gas over-the-fence from the neighbouring world-scale refinery operated by a joint venture between CNOOC (China National Offshore Oil Corporation) and Shell in Huizhou City, China. In deciding to go the WSA route, Bestgrand Chemical Group says that it has focused on the environmental benefits as well as the high energy efficiency and heat recovery of the process. The company predicts that it will reduce carbon dioxide emissions by 220,000 t/a and reduce sulphur dioxide (SO_2) emissions to a level 50% lower than that required of the sulphuric acid industry. The process converts more than 99.9% of the sulphur in the off-gases into commercial grade sulphuric acid. The technology was licensed from Haldor Topsoe, which has licensed 68 WSA plants in China since 2000, of which 54 are already on stream, and 14 are under construction.

INDIA

Grasim to expand acid production

Grasim Industries, part of the Aditya Birla Group, has received clearance from the Environment Ministry for an expansion at its Vilayat fibres production unit. The $400 million expansion project will increase production at the viscose stable fibre (VSF) plant at Vilayat, one of four such plants that the company operates in India, two of which are sited in Gujarat state. The company plans to increase the VSF capacity of VSF from 127,750 t/a 255,500 t/a, as well as setting up a facility for solvent spun cellulosic fibre with a production capacity of 36,500 t/a. This will also entail expanding production capacity at the sulphuric acid plant at the site from 102,000 t/a to 182,500 t/a, as well as expanding carbon disulphide production from 23,725 t/a to 34,675 t/a and captive power plant capacity from 25 MW to 55 MW. The expansion will take place within the existing 222 hectare site at Vilayat.

Reduction in tax on phosphoric acid

The Indian government has reduced the rate of Goods and Services Tax (GST) on phosphoric acid from 18% to 12%. The move follows representations from the Indian fertilizer industry that the 18% tax on acid inputs to diammonium phosphate (DAP) production (India imports most of its phosphoric acid requirement) was too high compared to the 5% GST tax on fertilizer production, leading to working capital being tied up in unused input tax credits and cash flow issues for fertilizer producers.

CANADA

Nutrien to stop buying phosphate from Western Sahara

Newly merged Agrium and PotashCorp venture Nutrien says that it intends to stop buying phosphate rock from Western Sahara, according to Chuck Magro, Nutrien president and CEO, speaking at an investor conference in British Columbia. Agrium's import contract with Moroccan phosphate major OCP will end during 2018, he said, ending imports into Canada. The company is still considering what to do with its import contract via PotashCorp, which takes rock into Baton Rouge, Louisiana.

SOUTH AFRICA

Restart for phosphate operation

Phosphate miner Kropz SA says that it will re-start mining at its Elandsfontein phosphate project before the end of 2018. The project, on the west coast of South Africa, was commissioned in 2017 but a combination of low phosphate prices, delays in gaining water permits and operating issues led to the decision to place the facility on care and maintenance in September. According to company CEO Ian Harebottle, returning the facility to production will require a revised plant design which can accommodate the ore body, and raising new capital. The latter may come from South Africa's Industrial Development Corporation, private equity or possibly a public stock offering.

Elandsfontein is the second largest phosphate deposit in South Africa, after

Foskor's Phalaborwa operation mine. It has a 15 year lifespan with the capacity to produce 1.35 million t/a of phosphate rock concentrate.

SERBIA

RTB Bor increases output at Veliki Krivelj

RTB Bor says that production of copper ore at its Veliki Krivelj open pit mine increased by 40% year-on-year to 855,000 tonnes in January. The company aims to produce 830- 900,000 tonnes per month of copper ore this year, close to the mine's maximum capacity. State owned RTB Bor completed an upgrade of its smelter acid plant in November 2017 which tripled capacity from 50,000 m^3 per hour of sulphur dioxide (SO_2) to 155,000 m^3/hour. RTB Bor will use the additional sulphuric acid for fertilizer production.

AUSTRALIA

BHP ramping up production at Olympic Dam

BHP is ramping up operations at Olympic Dam to full capacity in 1Q 2018, following a $350 million smelter upgrade project last August, according to the company. Smelting operations resumed late last year, BHP says, with the first anode cast from the flash furnace in December. Operations will continue to ramp up to full capacity in first quarter of 2018. BHP has also undertaken major upgrade works on the refinery, concentrator, and other key infrastructure and site technology at Olympic Dam. Copper dropped from 203,000 tonnes in the 2015/16 financial year to 166,000 tonnes in 2016/17, and is expected to be 150,000 t/a in 2017/18 before increasing to 215,000 t/a in 2018/19 and up to 280,000 t/a by 2022/23, with a concomitant increase in sulphuric acid production to 840,000 t/a.

Port Pirie restarts after upgrade

Nyrstar has re-started its smelter at Port Pirie, north of Adelaide, after a A$600 million investment to cut pollution and ensure its long-term viability. The upgrades include moving to a completely enclosed furnace design to capture dust and sulphur dioxide emissions which would result in a markedly improved environmental footprint, according to the company. Port Pirie produced 59,000 tonnes of sulphuric acid in 2016, according to Nystar figures. The upgraded acid plant is an Outotec double conversion double absorption design, and has a capacity of 1,000 t/d of 98.5% acid.

IRAN

Copper expansions inaugurated

President Hassan Rouhani and Iran's Minister of Industries, Mining and Trade Mohammad Shariatmadari have inaugurated a series of projects in the Iranian copper industry under the auspices of the Iranian Mines and Mining Industries Development and Renovation Organisation. NICICO is the leading copper producer in the Middle East and North Africa region, with 14% of Asia's copper deposits and about 3% of global reserves.

The new production projects include a flash smelter with a capacity of 282,000 t/a of copper anode; the Khatunabad Copper Smelter with an annual capacity of 200,000 t/a of copper cathode; the Sarcheshmeh copper plant's new converter furnaces' gas discharge system and the expansion of Sarcheshmeh's sulphuric acid plant capacity to 300,000 t/a. Sarcheshmeh is the world's second largest open-pit copper mine.

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People

The Sulphur Institute (TSI) has announced the selection of **Sarah Amirie** as the organisation's new director of operations. In this role, Ms. Amirie will oversee member relations, third party vendor services, and office management. Robert McBride, TSI president and CEO, remarked: "we look forward to having Sarah's experience, which will enhance TSI programs and operations." Ms. Amirie has previously worked as an executive assistant, treasury analyst, and software development technician throughout several departments in the federal government prior to joining TSI. She has a bachelor's degree from Marymount University and a Certificate in Computer Software Engineering from George Washington University.

AMETEK Land has appointed **Christopher Leonard** to the role of Director of Development and Product Management. Mr. Leonard has over 20 years of experience in mechanical and process engineering gained in the oil and gas, chemical, energy, and mining sectors. He has held roles in industrial application engineering and product commercialization of instrumentation from concept to market-leading brands and has worked for a variety of global industry heavyweights, including Hydratight, Bridon International and most recently Oxford Flow. In his new role, he will head the company's global industry management and design engineering teams. Development efforts will focus on bringing new products to market that will help industries meet ever evolving quality requirements coupled with tighter emissions controls and reduced energy consumption targets.

"We are pleased to have Chris join AMETEK Land," said Justin Smith, managing director. "He has extensive experience in product development and management gained across a number of industries that will be invaluable to this role in fast tracking the development of market-focused and customer-led new products from concept to global brand leadership."

As a result of Mr. Leonard's appointment, **Dr. Peter Drögmöller** takes up the new position of Director of Innovation and Technology. Dr. Drögmöller has a wealth of industry and product knowledge in industrial infrared camera systems for challenging applications and harsh environments. Dr. Drögmöller will continue to develop AMETEK Land's innovation relationships with strategic partners, universities and research centres globally to ensure that the company stays at the forefront of technology and remains the number one choice for temperature measurement and emissions monitoring instrumentation around the world.

The Mosaic Company says that **Rich Mack** will step down from his position as executive vice president and chief financial officer, and leave the company in May of 2018. **Tony Brausen** will serve as senior vice president – finance and interim CFO, effective immediately, until the position is filled permanently. He will also serve as the Company's designated principal accounting officer. Tony has led Mosaic's accounting, financial analysis and reporting, treasury, tax, information technology and business unit finance teams.

"On behalf of Mosaic's Board of Directors and our Senior Leadership Team, I would like to thank Rich for his 24 years of dedicated service and his contribution to many aspects of the company, from his Cargill years prior to Mosaic's formation through the very promising Vale Fertilizantes acquisition," said Joc O'Rourke, President and CEO. "Rich advanced many strategic initiatives for Mosaic and conducted himself and led the CFO organization with the highest ethical standards and integrity. Rich has a broad network and is well respected at Mosaic and by outside constituents. We wish him all the best in his future endeavors. We are pleased to have Tony serve as interim CFO, and he will continue in an advisory capacity to the permanent CFO.

Calendar 2018

MARCH

12-14
Phosphates 2017, MARRAKESH, Morocco
Contact: CRU Events
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

18-21
Middle East Sulphur, ABU DHABI, UAE
Contact: CRU Events
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

19-23
Sulphur Experts Technical Training Course, KUALA LUMPUR, Malaysia
Contact: Sulphur Experts Training Coordinator
Tel: + 1 281 336 0848
Email: Seminars@SulphurExperts.com

APRIL

29-MAY 3
SOGAT 2018, ABU DHABI, UAE
Contact: Dr Nick Coles, Dome Exhibitions
Tel: +971 2 674 4040
Email: nick@domeexhibitions.com

30-MAY 4
Sulphur Experts Technical Training Course, KEMAH, Texas, USA
Contact: Sulphur Experts Training Coordinator
Tel: + 1 281 336 0848
Email: Seminars@SulphurExperts.com

JUNE

6-7
European Sulphuric Acid Association General Assembly, TALLINN, Estonia
Contact: Patricia de Hertogh, CEFIC,
Avenue E. van Nieuwenhuyse,
4/2, B-1160 Brussels, Belgium
Tel: +32 (0)2 676 7253
Email: pdh@cefic.be
Web: www.sulphuric-acid.eu

8-9
42nd AIChE Annual Clearwater Conference 2017, CLEARWATER, Florida
Contact: Perry Alonso,
AIChE Central Florida Section
Email: vice-chair@aiche-cf.org

18-20
86th IFA Annual Conference,
BERLIN, Germany
Contact: IFA Conference Service,
28 rue Marbeuf, 75008 Paris, France.
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

JULY

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

NOVEMBER

5-8
Sulphur 2018 Conference and Exhibition, GOTHENBURG, Sweden
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The centre of the sulphur world?

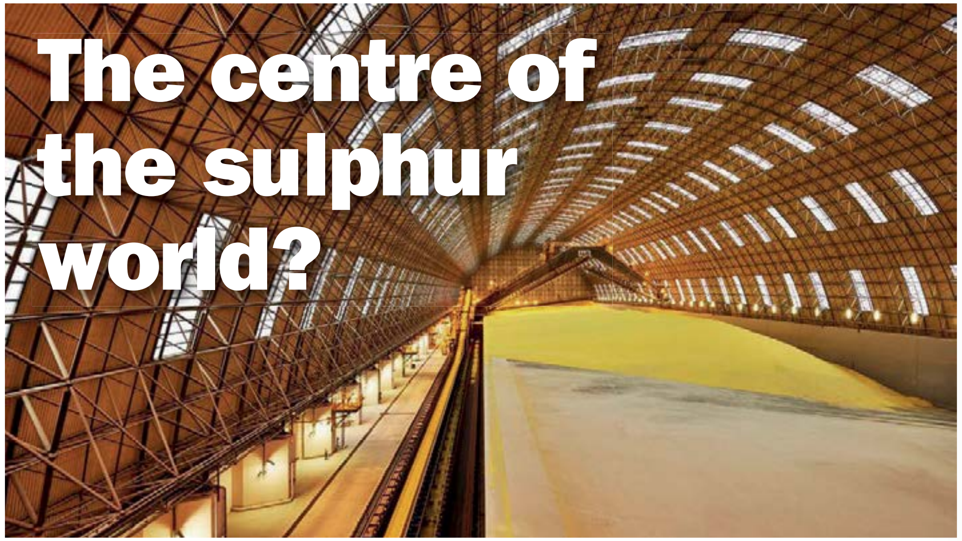

PHOTO: AL HOSN GAS

Above: Sulphur storage at the Shah project, Abu Dhabi.

Tapping of sour gas fields and continuing refinery expansions will see the Middle East continue to become increasingly dominant on the sulphur export scene over the next few years.

Over the next five years, annual global sulphur production is forecast to increase by about 10 million tonnes, and more than 50% of this growth will be in the Middle East. New refinery capacity and continuing expansions of sour gas production in order to provide power to rapidly increasing populations will drive this increase, and in spite of some increases in phosphate processing which will lead to new demand in Saudi Arabia, most of this extra sulphur seems destined to find its way onto global markets.

Abu Dhabi

Abu Dhabi has been at the forefront of new sulphur production in the region over the past few years, with production rising to 6 million t/a in early 2017 due to new production from the Habshan and Shah processing plants. While there are two refineries in the Emirate – one at Ruwais and a small and relatively simple processing facility at Abu Dhabi itself, most of this sulphur production has come from processing of sour gas reserves. Refinery sulphur production in Abu Dhabi mainly comes from Ruwais East and West (total 800,000 bbl/d capacity – the 417,000 bbl/d expansion started up in 2015). Sulphur recovery is a relatively modest 30 t/d at Ruwais.

Abu Dhabi's continuing move to monetise its sour gas resources, conversely, has generated extremely large volumes of sulphur. Abu Dhabi continues to rapidly expand – the Emirate's population reached an estimated 3 million in 2016, and is continuing to grow at around 5-8% per year, which would take it to more than 6 million people by 2030. The country's Economic Vision 2030 plan envisages a huge increase in natural gas production to feed electricity generation in order to cope with these new people. Some 98% of Abu Dhabi's electricity comes from natural gas-based generation, and the Emirate already imports 2 bcf/d of gas along the Dolphin Pipeline from Qatar.

There is a $110 billion plan for developing new gas production and infrastructure. Projects on the go currently include continuing expansion of the Integrated Gas Development project, which gathers gas from a number of fields to a processing site at Habshan. The Habshan V site currently processes 2.3 billion scf/d of gas to produce 1.1 billion scf/d of sales gas and 5,200 t/d of sulphur, and this year it is due to be expanded by a further 400 million scf/d with tie-ins from the Bab North East development.

The flagship Shah project, developed by Al Hosn Gas, a 60-40 partnership between the Abu Dhabi National Oil Co (Adnoc) and Occidental Petroleum, and which began operations in 2015, is also due for a 50% expansion to 1.5 billion scf/d, and plans have been floated for this to ultimately be doubled. The 50% expansion, which is believed to be looking towards a 5-year timescale (ca 2022) could see sulphur production at Shah increase to 14,500 t/d.

In the meantime, work continues on offshore sour gas projects, at Hail, 100km west of Abu Dhabi city, Ghasha and Dalma – the so-called North West Area. Bechtel (UK) was awarded the Hail & Ghasha front end engineering and design contract and TechnipFMC the Dalma contract, both to be completed next year. The ultimate aim is to produce collectively 1 billion scf/d of sales gas in the second half of the next decade in order to provide sufficient for electricity generation for another two million new homes, at an estimated cost of $20 billion, including construction of up to 11 offshore islands for recovery and processing sites – the water is relatively shallow (about 15 metres depth) but includes an important marine protection zone. Adnoc is reportedly close to awarding five technology licensor contracts, covering gas treatment; a sulphur recovery unit (SRU); natural gas liquids; condensates recovery and hydrogen generation.

Finally, there is the Bab sour gas project, from which Shell pulled out in 2016. Bab is an onshore field 150 km southwest of Abu Dhabi city. The original plan was a $10 billion mirror of Shah, processing 1 billion scf/d of gas to generate 500 million scf/d of sales gas and probably a similar amount of sulphur by 2020. While Shell's exit has dented the project, Adnoc insists that it is continuing to pursue it.

This rapid expansion in sulphur production has turned Adnoc into the world's largest exporter of sulphur and as a consequence, Adnoc has, albeit perhaps of necessity, decided to see sulphur as a strategic asset rather than as a problem.

Most recently, Adnoc has signed a sulphur supply deal with Morocco's OCP, running to 2025, with a steady increment in supply from Abu Dhabi to Morocco over that time. Morocco imported 2 million t/a of sulphur from Adnoc during 2016.

Bahrain

Bahrain's sulphur production comes from refining, at the Bahrain Petroleum Company (Bapco). Bapco's ageing refinery at Sitra is due for an expansion over the next few years. A consortium of TechnipFMC, Samsung and Tecnicas Reunidas has won the $4.2 billion EPC and commissioning contract to expand the refinery from 267,000 bbl/d to 360,000 bbl/d by 2022. With Bahrain's own oil reserves running down, the Bapco refinery is primarily supplied by pipeline from neighbouring Saudi Arabia, and a key component of the expansion will be the associated expansion in pipeline capacity from the Abqaiq processing hub in Saudi Arabia from 230,000 bbl/d to 350,000 bbl/d, due in 2018. A further 500 t/d of additional sulphur recovery capacity forms part of the refinery expansion, taking Bahrain from its current 150-160,000 t/a or so of production to double that at 320,000 t/a.

Iran

Iran produces sulphur from four refineries, at Tehran, Tabriz, Bandar Abbas, and Esfahan, as well as the Razi and Kharg petrochemical complexes, but as with many of the countries of the region, most of its sulphur production has come from natural gas processing. There are three sour gas processing complexes – at Khangiran (Hasheminajad) near Mashhad in the northeast of the country, at Ilam in the west near the Iraqi border, and at Assaluyeh, where the gas from South Pars is brought ashore, and Assaluyeh and Khangiran are the two largest of these. Total output ran at about 1.7 million t/a from a capacity of 2.2 million t/a, and has slowly increased as new phases of South Pars come on-stream.

The South Pars project has proceeded in 28 development phases involving gas production and associated onshore facilities, including gas and condensate processing and downstream petrochemical works. The final phase, the long-delayed Phase 11, is now likely to be completed in 2021-22, with a $4.8 billion agreement by Total and China National Petroleum Corporation signed in late 2016 with Iran's Petropars. Sulphur production could rise another 500-600,000 t/a over that period.

Iran says that it also has plans to revamp its ageing oil refineries – the country has suffered from a chronic shortage of refining capacity and has actually often had to resort to importing gasoline even while it was exporting oil. These would obviously also be a major boost to sulphur capacity – Iran currently mainly produces gasoline to Euro-4 standards at Shazand Arak, Isfahan and Tabriz refineries, and Euro-3 at the others, but there is an upgrade in progress at Bandar Abbas and Lavan. NIOC puts Iranian refining capacity at 2.1 million bbl/d, but the government aims to increase this to 3.4 million bbl/d by 2025.

However, various uncertainties remain over all of these projects, not least because of the political climate in the region which has seen Iran pitted against Saudi Arabia in a series of proxy conflicts, in Yemen, Syria and elsewhere. Israel and the Trump administration's concerns about the Iran nuclear deal could see American sanctions return, and international banking restrictions continue to make getting money into and out of Iran extremely difficult.

Kuwait

Kuwait's sulphur production runs at about 800,000 t/a, with refining providing most of this. Kuwait has had ambitious plans to increase its oil and gas production for many years, most notably Project Kuwait, which was to increase oil production to 4 million bbl/d by 2020. While there has been some improvement from previous figures (actual production in 2016 was 3.1 million bbl/d), laws preventing foreign ownership of oil facilities and bureaucratic delays have pushed many of these projects back. The consequence has been a growing shortfall in natural gas to meet local demand, and consumption has moved ahead of production. Now, as well as giving the go-ahead to a new LNG import terminal, the Kuwait Oil Co has launched a new Upstream Strategic Objective 2030 which aims to maximise production from existing associated gas fields, as well as tapping into sour, non-associated gas fields, especially in the northern, Jurassic formation. Engineering, procurement and construction companies have been invited to submit bids before the end of February 2018 to lift non-associated gas production from its current 180 million cfd to 510 million cfd, along with 200,000 bbl/d of light oil. The tender follows two contracts signed in 2017 worth more than $1 billion with Schlumberger for the development of oil and gas facilities at the East Raudhatain field, as part of the second phase of the Jurassic gas project. Black&Veatch has been awarded the licensing, FEED, operation, and maintenance support services for the gas processing section at Jurassic Gas Facility 1, including three parallel, identical 135 t/d SRUs with dedicated tail gas treatment units. Siirtec Nigi is designing and supplying two modular SRUs for the Sabriya and East Raudhatain Gas Treatment Plants, each with a capacity of 200 t/d of liquid sulphur.

More new sulphur production from Kuwait is projected to come from the expansion of refining capacity in the country via the Clean Fuels Project, which involves the upgrade and integration of the Mina Abdulla (MAB) and Mina Al Ahmadi (MAA) refineries, increasing the combined capacity of the refineries from 736,000 bbl/d to 800,000 bbl/d, and lowering the sulphur content of

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petroleum products. There is also a new refinery being built at Az Zour, which will replace the Shuaiba Refinery. The Kuwait National Petroleum Company (KNPC) says the first phase of its liquid sulphur treatment project at Mina al-Ahmadi has been completed. The facility includes four storage tanks for liquid sulphur, with a total capacity of 18,000 tonnes, as well as 5,000 t/d of granulation facilities and a warehouse with a capacity of 145,000 tonnes of solid sulphur, together with a jetty for loading and export of the sulphur – Kuwait's first facility for production, storage and export of solid sulphur, and will handle liquid sulphur from the KNPC Clean Fuels Project and facilities of the Kuwait Oil Co. The Clean Fuels Project is due to be completed this year. Meanwhile Enersul is supplying four granulators for the Az Zour project, each with a capacity of 1,250 t/d, which will be delivered in the first quarter of 2018. Overall completion of Al Zour phase 2 is set for May 2019.

Qatar

Qarar mainly processes slightly sour gas from the North Field at its huge LNG and GTL complex at Ras Laffan, on the northern tip of the Qatar peninsula. Sulphur recovered from these facilities is sent to the Common Sulphur Facility where it is formed and exported. Total sulphur recovery and forming capacity at Ras Laffan is approximately 3.5 million t/a, with actual production just over 2 million t/a, representing most of Qatar's 2.3 million t/a of production. Qatar, already the world's largest LNG exporter, has plans to expand its current LNG production and export from 77 million t/a to 100 million t/a by 2022 after a moratorium on new gas-based projects that nearly saw Qatar overtaken by other LNG producers such as Australia. Most of Qatar's new gas and hence sulphur is due to come from the RasGas Barzan LNG project, but an undersea gas leak discovered in October 2016 has delayed commissioning of the first phase of the project, and current estimates put completion at the end of 2018 or start of 2019. Once the second phase of the project is on-stream, and LNG production rises to 100 million t/a, sulphur production could rise as high as 3.5 million t/a in Qatar.

The gas expansions will all necessitate an increase in Qatar's sulphur output. Enersul says that it has been awarded an equipment supply contract from Doha Petroleum Construction Co. Ltd. for the Qatargas Common Sulphur Project Expansion at Ras Laffan. Enersul will supply two 1,250 t/d GXM1™ sulphur granulation units in the second quarter of 2018, for a total additional forming capacity of 825,000 t/a. Qatar has also shifted responsibility for sales and marketing of its sulphur to the Qatar Chemical and Petrochemical Marketing and Distribution Company (Muntajat) as from January 1st 2018.

Table 1: **New sulphur production from the Middle East, 2017-2022, million t/a**

Country	Refining	Sour gas	Total
Abu Dhabi	0.1	0.5	0.6
Bahrain	0.15	0	0.15
Iran	0.1	0.55	0.65
Kuwait	1.6	0.25	1.85
Qatar	0	0.7	0.7
Saudi Arabia	0.5	2.1	2.6
Total	**2.45**	**4.1**	**6.55**

Source: BCInsight

Saudi Arabia

In common with other countries in the region, such as Abu Dhabi and Kuwait, Saudi Arabia is looking to expand non-associated gas production in order to generate more electricity, and as with Abu Dhabi and Kuwait, this has also meant tapping into sour gas reservoirs. A major programme of sour gas development is now under way, with additional gas output from both onshore and offshore sour gas fields and several gas processing plants which are generating additional tonnages of sulphur. The Kursaniyah gas plant started up in 2012 and takes gas from the offshore Karan field to produce about 300,000 t/a of sulphur. Wasit, located north of Jubail, takes gas from the offshore Arabiyah and Hasbah sour non-associated gas fields and began operations in February 2016. At capacity, which should be reached this year, it will process 2.5 billion scf/d of sour gas to produce 1.7 billion scf/d of sales gas and 1.6 million t/a of sulphur.

Other new gas plants include 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, and sulphur production at capacity is expected to be 4,000 t/d (1.3 million t/a). Fadhili is due for completion in 2019.

On the refinery side, another component of Saudi Arabia's Vision 2030 strategy is greater processing of crude domestically for export of finished products. Saudi Aramco is in the process of constructing a wholly-owned refinery at Jizan with a capacity of 400,000 bbl/d, which will be completed by 2018, and which is liable to come to full operation in 2019. Sulphur output at Jizan is expected to be 400,000 t/a, and another 100,000 t/a will come from an expansion at Rabigh.

Regional sulphur balance

Table 1 shows the effect of all of these new additions to sulphur capacity. If all of these come to pass without significant delays, then there is the potential for an extra 6.5 million t/a of extra sulphur to come from the Middle East by 2022, and even a conservative forecast would be in the region of 5 million t/a. Set against this is the ramping up of the Wa'ad al Shamal phosphate project in Saudi Arabia, which will consume an additional 1.5 million t/a of sulphur to manufacture phosphoric acid, and the potential for a third project – although Ma'aden said recently that the target date of the latter is not until 2024, so this is unlikely to provide any additional demand during the next five years. Any other demand for sulphur in the region is likely to be incremental at best. Thus somewhere between 3.5 and 5 million t/a of new sulphur is likely to be coming from the Middle East by 2022. Adnoc has already indicated that it will be trying to sell much of its additional sulphur into Morocco via its deal with OCP, but the fate of the rest remains uncertain. Kuwait's recent investment in granulation capacity indicates that it is definitely looking to foreign markets for its sulphur.

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The Jorf Lasfar phosphate hub, Morocco.

PHOTO: OCP

North African phosphates

North Africa continues to be a major growth area for sulphur demand. As well as the continuing expansion of OCP's phosphate processing capacity there are also new projects in Tunisia and Egypt, and potentially also Algeria.

North Africa is to the world's phosphate industry what the Middle East is to the oil industry – while it is an important producer and exporter, it is even more important because of the share of global reserves that it contains. Global phosphate reserves are not as well characterised as oil, and subject to sometimes huge revisions, the two most recent of which have come this century. The first was in 2003, when Chinese phosphate reserves were first massively revised upwards to nearly 7 billion tonnes as the Chinese government began releasing more reliable figures, and then downwards again to 3.7 billion tonnes once these reserves were judged to be overestimated. But more eye catching still was the quadrupling of estimated global phosphate reserves that occurred in 2010 as a result of a study by the International Fertilizer Development Center (IFDC). Together with work by the US Geological Survey, this has now put global phosphate rock reserves at 67 billion tonnes, 80% of which is in North Africa, with Morocco and Western Sahara accounting for the vast bulk of this total, as shown in Table 1. North Africa is important now for the phosphate industry, and in the case of Morocco, for the sulphur industry, but more important still is the potential that it holds for future development.

Table 2 shows Africa's current phosphate production. Africa as a continent is responsible for 20% of the world's phosphate rock production, and 90% of that is in North Africa – the only other major African phosphate producing countries are Senegal and South Africa. The table shows that Africa is also responsible for 50% of traded phosphate rock on international markets, with North Africa accounting for 89% of that total, and Morocco alone 56%. However, Africa represents only 15% of finished phosphate production, as measured by its share of phosphoric acid manufacture, and Morocco (and South Africa) represent the lion's share of this.

Table 1: Global phosphate reserves, billion tonnes P_2O_5

Country	Reserves	Percentage
Morocco	50.0	75%
China	3.7	6%
Algeria	2.2	3%
Syria	1.8	3%
Jordan	1.5	2%
South Africa	1.5	2%
United States	1.4	2%
Russia	1.3	2%
Peru	0.8	1%
Saudi Arabia	0.8	1%
Tunisia	0.5	1%
Rest of world	1.5	2%
Total	**67.0**	**100%**

Source: IFDC, USGS

Table 2: African phosphate production, 2016 (million tonnes)

	Phosphate rock (tonnes product)		Phosphoric acid (tonnes P_2O_5)
	Production	Exports	Production
Algeria	1.3	1.2	0
Egypt	4.3	3.1	0.1
Morocco	26.9	7.9	9.5
Tunisia	3.7	0	1.0
Other Africa	4.5	1.8	2.1
Africa Total	**40.7**	**14.0**	**12.7**
World Total	200.0	27.6	83.3

Source: IFA

This figure used to be even smaller, before the beginning of Morocco's current push to capture more of the value chain by developing phosphate processing industries and phosphate fertilizer production domestically, and Morocco's success in doing so has encouraged other major reserve holders like Tunisia, Algeria and Egypt to see if they can follow suit. As the continent is relatively poor in terms of sulphur production – there is no sour gas production and what refineries there are are often relatively simple and produce little sulphur as by-product – this means that North Africa is likely to represent an increasingly important slice of demand for the world's sulphur.

Morocco

Morocco is the dominant nation in the world's phosphate industry. But although as noted above it probably has something like 75% of the world's phosphates under its control, it produces only 13% of the world's phosphate rock, and only 11% of finished phosphates, and the Moroccan state has taken a long term strategic decision to change this. Morocco's phosphate business is almost entirely in the hands of state-owned Office Chérefien des Phosphates (OCP). OCP represents a major sector of the country's economy, employing 20,000 people and accounting for 25% of Morocco's exports and about 3.5% of its GDP. Importantly, it also represents 30% of the international market for rock phosphate and 40% of that for phosphoric acid.

Most phosphate mining happens in the north of the country, at Khouribga and Gantour, where most of the country's proved reserves lie. There is also a smaller mine at Boucraa in Western Sahara. These in turn feed export facilities at Jorf Lasfar (for Khouribga), Safi (for Gantour) and Laayoune (for Boucraa).

In 2007, OCP began its expansion strategy, intended to run to 2025, during which time it would double its phosphate rock production and triple its finished fertilizer production. The first two phases of this expansion are now mostly complete, at an investment cost of $8 billion, and the third phase, from 2018-2025, is now under way, as well as expansions at the mine areas, especially Khouribga, where an extra 14 million t/a of mine capacity is being added to take capacity to 38 million t/a. OCP has instituted beneficiation plants and built two gravity-driven slurry pipelines to take phosphate concentrate from the mines to the coastal processing plants, the largest cluster of which is at the massive Jorf Lasfar Phosphate Hub (JLPH) complex. According to the company, the 38 million t/a capacity slurry pipeline connecting Khouribga to Jorf Lasfar has reduced phosphate concentrate cash cost to around $20/tonne, making OCP the lowest-cash cost rock producer globally.


PHOTO: OCP

DAP production in Morocco.

Jorf Lasfar

Jorf Lasfar is where most of the downstream investment is taking place. In cooperation with Jacobs Engineering via a joint venture company formed in 2010, OCP has built an additional four integrated DAP/MAP plants, each with a capacity of just over 1.0 million t/a, and each consuming 500,000 t/a of sulphur each to feed sulphuric acid and phosphoric acid capacity. These have roughly doubled MAP/DAP capacity at the site to just under 8.0 million t/a. OCP has also built two massive drying plants at the site to dry the slurry concentrate as it arrives from Khouribga so that it can maintain its exports of phosphate rock from Jorf at 10 million t/a at the same time that it increases finished phosphate production there.

Other new developments include upgrading of the existing Maroc Phosphore lines 3 and 4 at Jorf Lasfar (originally part of a joint venture with Brazil's Bunge but brought back into full OCP ownership a couple of years ago) by 10% each, as well as the addition of a new 500,000 t/a phosphoric acid plant due for commissioning in 2019, and the commissioning of a new 450,000 t/a phosphoric acid line at Laayoune in 2021, all of which will take OCP's phosphoric acid capacity to 8.4 million t/a at the start of 2022. In the meantime, the third and final projected phase of the Jorf Lasfar Phosphate Hub development, to begin in 2019 and running to 2025, will be to add another six 1.0 million t/a MAP/DAP complexes to bring OCP's total production of finished fertilizers from 12 million t/a to 18 million t/a, and bringing phosphoric acid capacity to over 11 million t/a. New processing lines are also planned for the port of Safi to handle later expansions of mining from Gantour.

Sulphur enhanced fertilizers

As well as increasing the volume of production of its basic mono- and di-ammonium phosphates and triple superphosphate (TSP), OCP is also attempting to branch out into more speciality fertilizers with a broader product offering via what it calls Performance Phosphate Products, including soluble fertilizers, animals feeds, micronutrient enhanced fertilizers, NPKs etc. The company estimates that in 2017 it sold 1.7 million tonnes of such speciality fertilizers. One of the ways in which OCP is seeking to differentiate itself is through offering sulphur-enhanced fertilizers. In 2016 it signed a deal with Shell to license the latter's Thiogro technology, which was installed at production lines in Jorf Lasfar during 2017. This allows OCP to incorporate micron-sized particles of elemental sulphur into its existing ammonium phosphate, NPKs and current sulphur-enhanced products.

Sulphur management

All of this expansion in phosphate processing will necessitate a similar expansion in sulphuric acid production and consumption, and hence sulphur imports. OCP has put considerable effort into making sure it is able to handle this side of the logistical equation, and the most recent fruit of this has

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been a long term sulphur sales agreement signed with the Abu Dhabi National Oil Company (ADNOC), which is itself facing an issue with steadily increasing sulphur output from its sour gas expansions at Shah and elsewhere. ADNOC now produces 6 million t/a of sulphur and is likely to increase that over the coming years. It has recently become the world's largest exporter of sulphur. Under the agreement, ADNOC, will supply OCP with an annually increasing amount of sulphur out to 2025. ADNOC exported more than 2 million tonnes of sulphur to Morocco in 2016.

Overseas ventures

Finally, OCP is also looking to develop partnerships in the wider world, especially across Africa. In November 2016 it signed a deal with Ethiopia to build one of the world's largest fertilizer plants, with an initial capacity of 2.5 million t/a. The plant, which is expected to start producing fertilizer in mid-2022, will import phosphoric acid from Morocco via a new terminal at Djibouti to produce NPKs at Dire Dawa, 250km east of Addis Ababa, using locally produced ammonia and potash. The first phase of the Ethiopia project will involve an investment of $2.4 billion, according to OCP, with a second $1.3 billion phase projected to increase the capacity of the facility to 3.8 million t/a by 2025.

OCP has also recently signed a deal with IBM to provide digital and IT services in sectors ranging from agriculture to industry across Africa. The new joint venture, TEAL Technology Services, will initially support OCP to accelerate its digital transformation and enhance efficiencies in its business operations, before moving to "create innovative solutions and services to drive digital transformation in industry and other sectors important to Africa's economic growth," according to the two companies.

Outside Africa, OCP has signed a joint venture agreement with India's Kribhco to develop a 1.2 million t/a greenfield NPK fertilizer plant in Krishnapatnam, Andhra Pradesh at a cost of $230 million. The joint venture is expected to be the first step in a broader strategic cooperation between both groups that could include Kribhco's investment in a phosphoric acid unit in Morocco.

Western Sahara

One fly in the ointment for Morocco has been the ongoing sovereignty dispute over Western Sahara, which has recently blown up into several lawsuits by Polisario, which claims to be the legitimate government of Western Sahara, to try and impound phosphate rock exported from Laayoune. This led to two ships being stopped, one in Panama and the other in South Africa (an attempt to detain a third shipment, in Uruguay, was rejected by the local court there). Ironically, exports form Laayoune represent only a fraction of OCP's rock exports every year, but the attendant publicity has led newly merged North American phosphate importer Nutrien to recently say that its goal is not to import rock sourced from Western Sahara.

Fig. 1: **Major phosphate producing facilities in North Africa**

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Algeria

After Morocco, moving eastwards along the coast we next come to Algeria, which has the world's third largest reserves of phosphates after Morocco and China, at 2.2 billion tonnes P_2O_5. Algeria's reserves are mainly the westward extension of Tunisia's Gafsa basin, with several prominent deposits running along the border with Tunisia. The Government-owned Entreprise nationale du Fer et du Phosphate (Ferphos) manages Algeria's production of iron ore, phosphate rock, and other key minerals, with phosphate mining conducted by its subsidiary Société des Mines de Phosphates SpA (Somiphos). Somiphos' key site is the Djebel-Onk complex, where there are an estimated 2.8 billion tonnes of phosphate rock deposits at 25-28% P_2O_5. Two main mines send phosphate rock to a 2 million t/a capacity beneficiation plant and onwards for export at the port of Annaba. A small amount is consumed domestically, but almost all of Somiphos' production is exported.

However, the government has ambitious plans to revitalise and expand Algeria's mining sector. The first fruits of this came via a new mining law passed in 2014, which revised the tax, fee and royalty framework for the sector, including the introduction of exemptions on value-added tax and customs duty for equipment, materials and services used for mining exploration and production.

In the phosphate sector, the aim is to open new mines at the Bled el Hebda deposit in the north of the country, where there are reckoned to be 800 million tonnes of phosphate rock. In 2016, Indonesian firm Indorama signed three deals worth a total of \$4.5bn with state-owned Asmidal and Manal to develop the mine along with downstream processing facilities. The new mine, a joint venture between Indorama and Manal, would ultimately produce 6 million t/a of rock at capacity, multiplying Algeria's phosphate production fivefold. The associated fertilizer facility would include 3,000 t/d of diammonium phosphate production (Algeria already exports ammonia and so would have plenty to spare for domestic DAP production), 1,500 t/d of phosphoric acid production, and 4,500 t/d of sulphuric acid production in the first phase, with the potential for two similar complexes to follow later if the phosphate mine expands to full capacity.

The initial target date for the complex to be up and running was 2019, but given how long it has taken Algeria to reach this stage, it seems certain that this date will slip.

Tunisia

Tunisia's reserves of phosphate rock are much smaller than its neighbours to the west, but by contrast with Algeria it has put much more effort into developing them, and in 2010 Tunisia was the world's fifth largest producer of phosphate rock, after China, the USA, Morocco and Russia, producing 8.1 million tonnes of rock. Two state owned companies operate Tunisia's phosphate sector; phosphate mining company Compagnie des Phosphates de Gafsa (CPG) and its downstream customer and processed phosphate producer Groupe Chimique Tunisien (GCT). CPG has about 8.4 million t/a of phosphate rock capacity at five mines around the Gafsa area. The rock is taken by rail to the port of Sfax where about 1 million t/a is exported, as well as to downstream production sites at Gabes, La Skhira, Sfax and M'dhilla, all of them operated by GCT, including triple superphosphate production at Sfax and M'dhilla, and phosphoric acid (including merchant grade acid) at Gabes and Skhira, as well as downstream diammonium phosphate production at Gabes. A 360,000 t/a new phosphoric acid plant came on-stream at Skhira in 2013, a joint venture with Indian fertilizer manufacturers Coromandel International Limited and Gujarat State Fertilisers and Chemicals Ltd (GSFC), each with a 15% stake, and Tunisia's GCT and CPG, with the remaining 70% between them. The joint venture company is known as Tunisian-Indian Fertilizers (TIFERT) and exports its entire output to India as part of the JV agreement. In order to process the phosphates, Tunisia's sulphuric acid capacity is 1,100 t/d at Sfax, 1,500 t/d at M'dhilla, 8,400 t/d at Gabes and 3,500 t/d at Skhira, for a grand total of 14,500 t/d of acid or 4.8 million t/a, requiring 1.6 million t/a of sulphur at capacity.

While Tunisia has the second largest processed phosphates capacity and sulphur requirement in North Africa, it has been plagued since 2010 by unrest and strikes which have hit phosphate production hard. Tunis was the cradle of the 'Arab Spring' which saw the ousting of its president Zine El Abidine Ben Ali in 2011. Unemployment and wages were a major cause of the discontent, and the phosphate industry – the country's major foreign currency earner – became a target for protestors. Tunisia's phosphate output fell to 2.5 million tonnes in 2011, and has never recovered beyond 3.8 million t/a since then. Tunisia has had nine governments in that time, but not one seems to have been able to tackle the country's deep economic issues, and a new round of strikes and blockades began at the start of February 2018. While the government has tried to use the phosphate industry as a source of jobs, more than doubling the workforce from 13,000 to 27,000 people, this has made the country's phosphate exports less competitive at a time when new low cost production is coming on-stream in Morocco and Saudi Arabia.

Table 3: North African sulphur imports, million t/a

	2016	2021*
Algeria	0.0	0.4
Egypt	0.2	0.9
Morocco	5.0	7.0
Tunisia	0.9	2.1
Total	**6.1**	**10.4**

** potential maximum, at capacity*

Source: BCInsight

Tunisia has plans for CPG to upgrade phosphate production as well as additional downstream processing at M'dhilla via an 800,000 t/a triple superphosphate plant. The latter – M'dhilla II – is due to come on-stream this year. It includes 200,000 t/a P_2O_5 of merchant grade phosphoric acid production.

Egypt

Egypt produced 4.3 million tonnes of phosphate rock in 2016, making it the seventh largest producer in the world after China, the USA, Morocco, Russia, Jordan and Brazil, although the country was only just ahead of rapidly increasing production in Saudi Arabia. Egypt has the capacity to produce more than this and some years has produced over 6 million t/a. The country has some of the lowest production costs for its phosphate rock, and the government has decided to expand production and, like Morocco, capture more of it via downstream processing of phosphate rock.

Egypt's phosphate deposits occur in a wide belt across the centre of the country, stretching from the Red Sea inland through the Nile Valley and into the New Valley in the Western Desert. Egyptian phosphate is however generally lower grade (20-30% P_2O_5 is typical, although some deposits reach 34%). Mining is in the hands of several companies, but the two largest are the state owned Phosphate Misr and the military-owned El Nasr Company. Phosphate Misr operates the Abu Tartour mine in the New Valley area, opened in 1979, which has some of the most concentrated deposits (26-31% P_2O_5), and where annual production is around 2.1 million t/a from low cost (\$15-20/t f.o.b.), open cast operations. The other major mines are in the Nile Valley, around Sabaiya, also surface mines, now operated by El Nasr. The National Co. for Mining & Quarries (El Wataneya) also has a mine at Aswan with a capacity to produce 600,000 t/a of rock which re-started production in 2016.

Mining expansion is planned for Abu Tartour, adding 3 million t/a of phosphate rock production capacity by 2022. Downstream projects to fall out of the current push towards monetising phosphate production include the major El Nasr Intermediate Chemicals (a subsidiary of El Nasr Co) Ain Sukhna project, which will include 450,000 t/a P_2O_5 of phosphoric acid production, with downstream diammonium phosphate and 470,000 t/a triple superphosphate capacity on the Red Sea coast. This is being funded with foreign partners including Italian and Chinese companies, and is due to come on stream in 2019. There is also Phosphate Misr's El Wadi project, which will have 520,000 t/a P_2O_5 of phosphoric acid capacity, and which is due to come on-stream in 2021.

The role of sulphur

Neither Algeria or Tunisia have any appreciable elemental sulphur production, and Egypt and Morocco each produce only a modest amount (typically less than 100,000 t/a). The large scale growth of domestic phosphate industries thus requires large volumes of sulphur imports in order to feed sulphuric and phosphoric acid production. As a result, Morocco has become the world's largest sulphur importer, and Tunisia still ranks among the top five in spite of the downturn in its phosphate industry. Egypt imports around 200-400,000 t/a. Algeria does not currently figure as a sulphur importer because it currently exports only phosphate rock and not processed phosphates. As a region, North Africa thus represented 6.1 million t/a or just under 20% of global sulphur imports in 2016, up from 14% in 2012, and mainly due to the start-up of the new plants at Jorf Lasfar in Morocco.

The expansions that have been discussed in this article could see that rise considerably over the coming years. Table 3 gives a deliberately over-optimistic potential projection of this, involving North African sulphur imports increasing by over 4 million t/a to nearly 10.5 million t/a in 2021. This figure depends upon all of the above projects coming to fruition with no delays, and an end to Tunisia's labour disputes, allowing idled capacity to come back on-stream. Of course, it is unlikely that all of these will be the case, and any potential oversupply in the global phosphate market would likely see the timescales slip for projects. Continued political wrangling in Tunisia and Algeria are also likely to lead to further delays. Nevertheless, the figures for Morocco, the largest importer, may well be close to the mark. North African phosphates look set to be an increasing source of demand for sulphur over the coming years. ■

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Ben Franklin bridge and Philadelphia skyline.

PHOTO: ULTIMA_GAINA/ISTOCKPHOTO.COM

Sulphur World Symposium 2018

The Sulphur Institute's annual World Sulphur Symposium comes to the Loews Philadelphia Hotel in Philadelphia, PA, from April 23rd – 25th 2018.

Following its move across the Atlantic to Dublin last year, The Sulphur Institute's (TSI's) annual World Sulphur Symposium is returning to the US in April. The Symposium is an annual conference that attracts international sulphur industry leaders from over 25 countries for two days of specialised speakers and networking events. Over 125 principal sulphur delegates are expected this year.

As well as the speaker presentations, an exhibition will be held as usual, this year held in the Regency Foyer outside Regency B, the TSI speaker session room. Coffee breaks will also be held in the Regency Foyer.

Symposium Schedule

23 APRIL 2018

09:00 - 11:00	TSI Annual General Meeting, Howe Room (33rd floor). *TSI Members only.*
18:00 - 20:00	Welcome Reception, Howe Room and Atrium (33rd floor). *Co-sponsored by Shell Sulphur Solutions and The Sulphur Institute.*

24 APRIL 2018

08:30 - 09:00	Coffee and Continental Breakfast *Sponsored by Oxbow Sulphur Inc.*
09:00 - 10:30	Speaker Session 1
10:30 - 11:00	Coffee Break
11:00 - 12:30	Speaker Session 2
12:30 - 13:30	Lunch *Sponsored by Savage Services Corporation.*
18:00 - 19:30	Evening Reception

25 APRIL 2018

08:30 - 09:00	Coffee and Continental Breakfast
09:00 - 10:30	Speaker Session 3
10:30 - 11:00	Coffee Break
11:00 - 12:30	Speaker Session 4
12:30 - 13:30	Lunch

MAIN SESSION PRESENTATIONS

China's "One belt, one road" initiative transforms global supply chains

David R. Meyer, Olin Business School, Washington University in St. Louis

China's "One belt, one road" (Belt & Road) initiative is transforming global supply chains, especially across Asia, the Middle East, and Europe, and also extending to Africa. The supply chain linkages are embodied in the Silk Road Economic Belt and New Maritime Silk Road. One key part of the initiative aims to propel economic development within Asia, a process never significantly supported by the countries of Asia or by external actors, especially in Europe and North America. The Asian Infrastructure Investment Bank (AIIB), which is organised like a typical multilateral development bank, is headed by an elite group of experienced financial and development executives. The bank is the financing vehicle for achieving intergovernmental cooperation. It serves as enabler of the development process and expansion of infrastructure. This seed money supplements even larger sums from governments and private sector actors who will supply most of the capital. AIIB, however, participates in only a small share of the projects; funding sources are diverse. Key infrastructure components include railroads, highways, telecommunications (fibreoptic lines), ports, power plants, and dams. This infrastructure is being integrated by sea and by land. It opens a large territory within Asia (e.g., Siberia, Kazakhstan, Mongolia), previously inaccessible or with poor infrastructure, to resource development. Successful implementation of this initiative will accelerate Eurasian, Middle East, and African development and lead to greater economic integration and restructuring of global supply chains. Numerous projects in Asia, Europe, the Middle East, and Africa are already underway. China's strategy is to draw on the global financial expertise in London and Hong Kong to identify and organize the vast amounts of capital that will be needed for "Belt & Road" projects. These capital flows will contribute to the internationalization of the renminbi. Global companies need to plan their approaches to participate in the "Belt & Road" initiative and to develop supply chain strategies that leverage this dramatic restructuring of interconnectivity across Eurasia, the Middle East, and Africa.

'Making America great again': implications for the US and global economies

John M. Urbanchuk, managing director, Agriculture and Biofuels Consulting, LLP

Austin Chamberlin, English statesman, scholar and brother of Prime Minister Neville Chamberlin is credited with introducing the phrase: "may you live in interesting times" in the 1930s, and it is difficult to imagine a more appropriate economic and political environment than today where it applies. The presentation reviews the economic revitalisation that appears to have accompanied the political revolution that ushered Donald Trump into the presidency, prompted by an unprecedented rollback of regulations, tax cuts intended to restore competitiveness and put money back into consumer's pockets, accelerated growth in output and improved employment environment. The outlook for the US economy is more positive now than at any time in recent years. Most of the other major world economies also are experiencing a wave of growth and the IMF is predicting world growth of 3.9% this year up from 3.2% two years ago. However, significant challenges and threats remain. Accelerated real growth is likely to increase demand for commodities and other materials and tight labour markets will push up labour costs. The result of this is likely to be a resurgence of inflation, which has been dormant for the better part of the last decade. Concerns about overheating and inflation are expected to lead to higher interest rates. On the political front threats range from the possibility that the president may be indicted for obstruction of justice, continued unrest in the Middle East, war with North Korea, the implications of Brexit for Europe, and threats from potential trade wars.

IMO 2020: a sea change is coming

Ralph Grimmer, Stillwater Associates

The International Maritime Organisation (IMO) is moving forward with its "IMO 2020 Rule" which will reduce the maximum sulphur content of marine fuel (aka bunker fuel oil) to 0.5 wt.% in areas outside of Emission Control Areas (ECAs) unless onboard stack gas scrubbers have been installed. This mandate was passed in 2008 as part of the MARPOL Annex VI rule, and will take effect on January 1st 2020. Implementation of IMO 2020 will have a pronounced impact on relative market prices for marine fuels, other refined products, and crude oil on a global basis. Beginning on January 1st 2020, marine fuel options will include compliant 0.5 wt.% sulphur marine fuel, high sulphur fuel oil (HSFO) in tandem with a scrubber or in violation of the rule, or an alternative fuel such as liquefied natural gas (LNG).

The impact of the rule and its market pricing will be keenly felt by all participants in the marine fuel chain – ship owners, marine fuel suppliers, refiners, and associated industry sectors. Ship owners must take into account many factors when determining how to comply with IMO 2020. Some of these factors include the cost of installation and operation of new equipment on their vessel(s), the age of the vessel, trading routes, market economics, availability of equipment, and the viability of exhaust gas scrubbers. Industry capital investments – scrubbers on board vessels and refinery resid upgrading – will be required and will look attractive if price differentials widen durably. Fuel suppliers, for their part, will have to adjust their marine fuels mix from 2018 through 2020 rollout and beyond in compliance with the Rule and market pressures from shipowners. Meanwhile, refiners will feel the impacts of the IMO 2020 Rule differently based on class. Refineries currently producing HSFO will be the most threatened by the Rule while those currently producing minimal HSFO will likely see IMO 2020 as an opportunity rather than a threat. In any case, all players in the supply chain will have to reckon with the effects of IMO 2020 sooner or later.

In his presentation, Ralph Grimmer will discuss compliance, enforcement, shipowner decision-making, market price and refinery implications, changes in the marine fuels mix, capital investments encouraged by the Rule, how IMO 2020 might be rolled out, and the potential impact on global sulphur production.

Caprolactam market review

Mark Victory, ICIS

The abstract of this paper was not available at the time of going to press.

Global sulphur and sulphuric acid market outlook

Claira Lloyd, David Tonyan, Argus Media

Claira Lloyd and David Tonyan from Argus will conduct a joint presentation, with Claira covering the sulphur market and David discussing sulphuric acid. Claira will assess this year's market, paying close attention to global near-term supply and demand drivers following sulphur's unexpected year in 2017, when the market saw Middle East f.o.b. spot prices hit five year highs and new buying parties enter the Chinese market. David will analyse the supply and demand factors driving the sulphuric acid market in 2018, amidst a tight global market early in 2018. He will touch on relevant projects on both sides of the balance, and look ahead to new trade flows developing throughout the world. Key factors this year include consumption levels in Chile and North Africa, and where traders will place Asian volumes. Strikes and copper prices are impacting both supply and demand in Chile, while OCP in North Africa continues to expand its phosphate capacity. European supply should see stability with no significant maintenances on the docket for 2018.The North American market has several new consuming projects either ramping up or scheduled to come on line and new terminals already scheduled or being considered on the west coast.

The outlook for phosphate markets: what's next?

Andy Jung, The Mosaic Company

The global phosphate market remains in a period of transition. Last year was characterised by new capacity ramping up in the Middle East and North Africa, offset later in the year by a slowdown in Chinese exports and the idling of Mosaic's Plant City facility. This presentation provides an overview of the aforementioned transitional changes, including how they're expected to influence the market in 2018, as well as detailing other key factors to watch that could have an outsized impact on the global phosphate supply/demand balance in 2018 and beyond.

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Sulphur recovery plant listing 2018

Sulphur's annual survey of recent current and future sulphur recovery unit construction projects maps the developing shape of brimstone production from fuel and gas processing plants worldwide.

Operating company	Operating site	Process type	Total new capacity	Licensor(s)	Lead contractor	Project type	Planned start-up date
ALGERIA							
Sonatrach	Tiaret, Hassi Messaoud	Claus, TGT, amine, SWS	14 t/d	n.a.	Amec Foster Wheeler	New	2020
ARGENTINA							
AXION Energy	Campana	Claus, TGT	2 x 30 t/d	PROSERNAT	PROSERNAT	New	2018
AZERBAIJAN							
SOCAR	Baku HAOR	Claus, TGT amine H_2S, CO_2	2 x 30 t/d	Tecnimont, UOP Amec Foster Wheeler	Amec Foster Wheeler	New	2021
BAHRAIN							
Bapco	Sitra Refinery	Claus, NH_3, amine SWS, AGRU	3 x 250 t/d	WorleyParsons	n.a.	New	2020
BELGIUM							
ExxonMobil	Antwerp Refinery	O_2 enrich, amine, TGT	325 t/d	WorleyParsons	Amec Foster Wheeler	Revamp	2018
n.a.	Antwerp	Claus, TGT	490 t/d	n.a.	Amec Foster Wheeler	Revamp	2018
BRAZIL							
Petrobras	Premium I	SuperClaus	2 x 240 t/d	Jacobs	n.a.	New	Cancelled
Petrobras	Premium II	SuperClaus	240 t/d	Jacobs	n.a.	New	Cancelled
Petrobras	Rio de Janeiro	SuperClaus	2 x 62 t/d	Jacobs	n.a.	Revamp	2018
CAMEROON							
SoNaRa	Limbe	SRU, SWS	17 t/d	Amec Foster Wheeler	KT Kinetics Tech	New	2018
CHILE							
ENAP	Aconcagua	EuroClaus	45 t/d	Jacobs	n.a.	Revamp	2018
ENAP	Biobio						
CHINA							
Jiutai Energy	Linyi, Shangdong	EuroClaus	32 t/d	Jacobs	n.a.	New	2018
Sinopec	Fujian	SuperClaus	513 t/d	Jacobs	n.a.	New	2018
Shaanxi Yancheng	Yulin, Shaanxi	EuroClaus	41 t/d	Jacobs	n.a.	New	2018
COLOMBIA							
EcoPetrol	Barrancabermeja	Claus, NH_3, amine	2 x 130 t/d	WorleyParsons	n.a.	New	On hold
CROATIA							
INA	Rijeka	Claus	95 t/d	WorleyParsons	n.a.	New	2019
EGYPT							
MIDOR	Alexandria	Claus	410 t/d	n.a.	n.a.	New	2018
FRANCE							
Total	Donges	SWS	n.a.	Amec Foster Wheeler	Amec Foster Wheeler	New	2021
Total	Normandy	SuperClaus	96 t/d	Jacobs	n.a.	Revamp	2019

Operating company	Operating site	Process type	Total new capacity	Licensor(s)	Lead contractor	Project type	Planned start-up date
INDIA							
Essar Oil	Vadinar	Claus, SCOT	675 t/d	Jacobs	n.a.	New	2019
Reliance	Jamnagar	O_2, NH_3, amine TGT	4 x 1,300 t/d	WorleyParsons	n.a.	New	2018
HPCL	Vishakhapatnam	Claus	2 x 360 t/d	n.a.	n.a.	New	2020
IOCL	Panipat	Claus, TGT	225 t/d	PROSERNAT	n.a.	New	2020
IOCL	Mathura	Claus, TGT	2 x 425 t/d	PROSERNAT	n.a.	New	2020
IOCL	Bongaigon	Claus, TGT	20 t/d	PROSERNAT	n.a.	New	2020
IOCL	Bathinda	Claus, TGT	750 t/d	PROSERNAT	n.a.	New	2019
INDONESIA							
PT Medco E&P	East Aceh	EuroClaus	48 t/d	Jacobs	n.a.	New	2019
PT Pertamina	Cepu	Claus, SCOT	122 t/d	Jacobs	n.a.	New	2018
Pertamina	Balongan	Claus, NH_3, H_2, amine TGT	1,100 t/d	Amec Foster Wheeler	n.a.	New	n.a.
IRAQ							
Turkish Pet Int	Mansuriyah	Claus, amine	230 t/d	WorleyParsons	n.a	New	2019
ISRAEL							
Bazan	Haifa Refinery	O_2 enrich	3 x 100 t/d	WorleyParsons	n.a.	Revamp	2018
KAZAKHSTAN							
Pavlodar Oil Chem	Pavlodar Refinery	Claus, TGT	180 + 260 t/d	Siirtec Nigi	Rominserv, Technip	New	2018
KUWAIT							
Chevron	Wafra	Claus, amine	2 x 218 t/d	WorleyParsons	n.a.	New	2018
KNPC	Al Zour Refinery	Claus	1,500 t/d	Amec Foster Wheeler	n.a.	New	2019
KOC	JPF	Claus, TGT	2 x 100 t/d	Siirtec Nigi	Schlumberger	New	2018
KOC	JPF	SmartSulf	2 x 100 t/d	PROSERNAT	PROSERNAT	New	2018
KNPC	Mina al Ahmadi	Claus, amine TGT	2 x 400 t/d	WorleyParsons	n.a.	New	2019
MALAYSIA							
Petronas	Johor	SuperClaus	3 x 470 t/d	Jacobs	n.a.	New	2019
MEXICO							
PEMEX	Duba	SRU	n.a.	n.a.	Amec Foster Wheeler	New	2018
PEMEX	Cadereyta	SmartSulf, NH_3	132 t/d	WorleyParsons	n.a.	New	On hold
PEMEX	Tula, Hidalgo	EuroClaus	3 x 640 t/d	Jacobs	n.a.	New	2019
NETHERLANDS							
Total/Lukoil	Zeeland	SWS	n.a.	Amec Foster Wheeler	Amec Foster Wheeler	Revamp	2020
NIGERIA							
Dangote Oil	Lekki Refinery	SuperClaus	2 x 115 t/d	Jacobs	n.a.	New	2019
OMAN							
OOC	Duqm Refinery	Claus, H_2, SWS, amine	3 x 355 t/d	Jacobs	Tecnicas Reunidas	New	2021
PERU							
Repsol	La Pampilla	2 x Claus, NH_3, O_2, H_2, amine, TGT	37 t/d	Amec Foster Wheeler	n.a.	New	n.a.
POLAND							
Grupa Lotos	Gdansk Refinery	O_2 enrich	2 x 60 t/d	WorleyParson	Tecnimont	Revamp	2018
QATAR							
Qatar Petroleum	Mesaieed	Sour gas, AGE, Claus, TGT	310 t/d	Worley Parsons	Petrofac/Black&Veatch Prosernat	Revamp	2018
RUSSIA							
Bashneft	Ufa	Amine, SWS	n.a.	Amec Foster Wheeler	n.a.	New	2023
Bashneft	Ufa	SmartSulf	115 t/d	PROSERNAT	n.a.	New	2018
Gazpromneft	Moscow	LPG treat, amine	n.a.	Amec Foster Wheeler	Amec Foster Wheeler	New	2019
Lukoil	Volgograd	NH_3, H_2, amine TGT, D'GAASS	2 x 76 t/d	Fluor	n.a.	New	2018
Marisky	Mari El Republic	SRU, TGT, amine	n.a.	Shell	Amec Foster Wheeler	New	Suspended

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Operating company	Operating site	Process type	Total new capacity	Licensor(s)	Lead contractor	Project type	Planned start-up date
RUSSIA continued							
Rosneft	Saratov	EuroClaus	283 t/d	Jacobs	UOP	New	2020
Orsknefteorg	Orsk	EuroClaus	2 x 99 t/d	Jacobs	n.a.	New	2018
Taneco	Nizhnekamsk	Claus, TGT	3 x 410 t/d	WorleyParsons	n.a.	Revamp	2019
SAUDI ARABIA							
PetroRabigh	Rabigh	EuroClaus	292 t/d	Jacobs	n.a.	New	2019
Saudi Aramco	Tanajib Gas Plant	Claus, O_2 enrich, amine	3 x 1,000 t/d	WorleyParsons	n.a.	New	2020
SERBIA							
NIS	Pancevo Refinery	Claus, NH_3, amine	170 t/d	WorleyParsons	n.a.	Revamp	2019
SINGAPORE							
SRC	Jurong Island	Claus, O_2 enrich, NH_3	145 t/d	WorleyParsons	n.a.	Revamp	On Hold
SRC	Jurong Island	SuperClaus	2 x 65 t/d	Jacobs	n.a.	Revamp	2019
ExxonMobil	Pulau Ayer	SuperClaus	400 t/d	Jacobs	n.a.	New	2020
SOUTH AFRICA							
Chevron	Cape Town	Claus, SCOT	2 x 45 t/d	Jacobs	Fluor	Revamp	2019-20
SOUTH KOREA							
Hyundai	Daesan	O_2 enrich	410 t/d	WorleyParsons	n.a.	Revamp	2018
S-Oil	Onson	Claus, amine, TGT, SWS	2 x 220 t/d	Amec Foster Wheeler	Amec Foster Wheeler	New	2018
SPAIN							
Cepsa	Algeciras	Claus, SCOT	280 t/d	Jacobs	n.a.	New	2019
BP Oil	Castellon	EuroClaus	2 x 45 t/d	Jacobs	n.a.	Revamp	2018
THAILAND							
Thai Oil	Sriracha Refinery	Claus, NH_3, Flexsorb	2 x 837 t/d	WorleyParsons	Amec Foster Wheeler	New	2021
TURKEY							
STRAS	Aliaga/Izmir	SRU, TGT, amine, SWS	463 t/d	Tecnimont KTI	Amec Foster Wheeler	New	2018
Tupras	Izmir	Degassing	73 t/d	Jacobs	n.a.	New	2018
Tupras	Izmir	EuroClaus	240 t/d	Jacobs	n.a.	New	2020
Tupras	Kirikale	EuroClaus	135 t/d	Jacobs	n.a.	New	2020
TURKMENISTAN							
Turkmenbashi Oil	Turkmenbashi City	SuperClaus	25 t/d	Jacobs	Hyundai	New	n.a.
UNITED ARAB EMIRATES							
IPIC	Fujairah	SRU, SWS, amine TGT	330 t/d	Amec Foster Wheeler	n.a.	New	2018
Al Hosn Gas	Shah	n.a.	4 x 1250 t/d	n.a.	Amec Foster Wheeler	New	2022
UNITED STATES							
Chevron	Richmond, CA	O_2 enrich	580 t/d	WorleyParsons	n.a.	Revamp	2018
UNITED KINGDOM							
Eni	Point of Ayr	Claus, amine, TGT	n.a.	WorleyParsons	n.a.	Revamp	2018
UZBEKISTAN							
Lukoil	Kandym	SuperClaus, TGT	2 x 405 t/d	Jacobs	n.a.	New	2018
Mubarek	Mubarek Gas Plant	Claus, amine	1,000 t/d	WorleyParsons	n.a.	New	2020
VENEZUELA							
PDVSA	El Palito	SRU, amine, TGT, SWS	250 t/d	Shell	Amec Foster Wheeler	New	2018
PDVSA	Puerto La Cruz	Claus, NH_3, amine	2 x 225 t/d	WorleyParsons	n.a.	New	2019
VIETNAM							
Bin Son Refinery	Dung Quat	Claus, SCOT, TGT, SWS	2 x 105 t/d	Jacobs, Amec Foster Wheeler	Amec Foster Wheeler	New	2019

KEY

AGE: Acid gas enrichment
AGRU: Acid gas removal unit
BTX: BTX destruction
Fuel: Fuel gas supplemental burning
O_2: Oxygen enrichment
NH_3: Ammonia destruction
H_2: Hydrogenation
SCOT: Shell Claus offgas treating
SRU: Sulphur recovery unit
SWS: Sour water strip
TGT: Tail gas treatment unit
n.a: Information not available

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The digital world of sulphuric acid

Simulator engines have come a long way from their humble beginnings. In this article Chemetics, Haldor Topsoe, NORAM and Outotec report on some of the latest developments and applications of simulation and modelling to improve the profitability, design and operation of sulphuric acid plants.

Process simulator programs have been widely adopted in chemical plant designs during the last two decades and the sulphuric acid industry is no different. Plant modelling using process simulators is an indispensable tool for process engineers, plant engineers and designers.

The classic application of simulators is for calculation of the mass and energy balance, which forms the basis of process flow diagram (PFD) development. The PFD is one of the key engineering documents that forms the basis for sizing the plant equipment, piping, and ducting. This type of application is typically known as static simulations as the problem is solved for a particular steady state.

Another application for process simulators is looking at the real time response of the plant when an input or parameter is changed. The model essentially runs in real time and mimics the behaviour of the actual plant. This type of application is known as dynamic simulation.

There are many types of process simulators but they are all essentially a mathematic solver (simulator engine) that requires the user to provide physical properties of the materials components (e.g. sulphur, sulphuric acid, air, water, etc.), definition of chemical reactions (e.g. S + $O_2 \rightarrow SO_2$), material and energy inputs/output, equipment models and economic information. This completed process model is then solved by the simulator engine which calculates the mass and energy balance with temperatures, pressures, compositions, costs, etc. for each stream solved as the output.

Before a process model can be used to simulate an existing process, it is important to validate all the assumptions, inputs/outputs, and property estimation methods by specialists experienced in the process in question.

Fig. 1: Modern sulphuric acid plant with process design optimised using modelling.

One of the major benefits of process simulators is that designers can look at the sensitivity of changes of various parameters once the basic plant model is set up in the simulator. The designer can adjust parameters to optimise the plant process design to achieve the client's objectives. This enables engineers to complete sophisticated design, development, analysis, and optimisation of plant designs before significant resources are committed for detailed engineering. This inherent benefit to quickly simulate different operating parameters of a sulphuric acid plant allows process engineers to not only design and optimise new greenfield plants but also to troubleshoot and debottleneck existing plants. By developing accurate models that simulate the effects of changes to the plant conditions, deviations and malfunctions can be simulated in the "virtual plant" to allow operators to quickly determine the root cause of the problem before the issue becomes catastrophic, forcing the plant to be shut down for repairs.

Process simulators allow actual plant operating data to be fed into the created plant model and allow the end user to quickly predict the expected performance of the plant. However, in many cases plant data that is collected is typically incomplete and at times inconsistent due to changes in operating conditions during data collection; the equipment may not be performing as originally designed due to wear, fouling or even premature failure, and there are many constraints that can't be input directly into the model. Some of the extra constraints are physical restrictions at the site, cost differences depending on existing equipment and its condition, and time to implement changes. To address these challenges, some process simulators can now connect to the plant control systems such as DCS, PLCs, etc. directly and collect plant data in real time. This improves the quality of the data input into the model but it is still up to the engineer to determine if the data reflects the actual operating conditions of the plant.

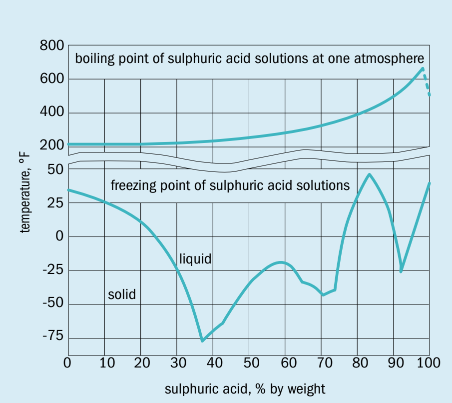
Limitations of process simulators

Despite the advances in process simulator technology, all process models created in the simulator are still only a representation of the plant in question, and they are not the exact replica of the plant. One of


PHOTO: CHEMETICS

Fig. 2: New Chemetics SARAMET® acid towers with modelling process design confirmed using plant operational data.

Fig. 3: **Freezing point of sulphuric acid solutions**[1]



the critical issues that is often overlooked even by experienced plant engineers or process designers is that when they see a result generated by the simulator, they assume it must be correct. Without first validating the model and its inputs, the output of the model can suffer from the classic "garbage in, garbage out" problem.

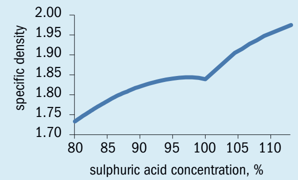
Fundamentally the results are based on the simulator engine executing the inputted calculations. The simulator engine will execute whatever it is told to, exactly as it is told to even if that makes no sense in the real world system that is being modelled. Examples where this can occur are errors in the connectivity between process units, incorrect shortcut calculations to improve convergence and calculation time, errors during data entry, invalid reactions, and using the wrong calculation methods or physical property models. Although most modern simulators have built-in error checking routines to warn the user with obvious input errors, it is still up to the engineer to ensure all the assumptions and parameters used in the model are appropriate for the situation.

When using a commercially available process simulator, it is critically important to validate that the property estimation methods used in the model are appropriate for the chemical process in question. Significant errors can result from either (a) incorrect physical property data that feeds to the property estimation calculation, or (b) inappropriate estimation methods to calculate the physical properties that are used. Reliable physical property data typically only exists for pure components, and selected common mixtures that exhibit close to ideal behaviour. Modern simulators have a large number of property estimation methods available for the user and some software packages even allow the end user to create their own property estimation equations to improve the accuracy of the property predictions.

It is critical for the process model designer to select appropriate property models for the chemical process to be simulated. In most cases no single property estimation method can predict properties for all the chemical components in a plant. Before selecting a property method calculation, the designer should check to ensure the method selected is appropriate for the mixture of the components, temperature and pressure of the process, and the availability of parameters for the calculations in these ranges.

For the case of simulating sulphuric acid plants it is particularly challenging because in the typical operating range of sulphuric acid plants (80-100 wt-% H_2SO_4), the fluid is considered non-aqueous and does not behave like ideal fluids, due to the various hydration states that exists. This makes modelling physical properties using traditional methods such as equation of state, activity coefficients, etc. difficult to reflect the actual real world data. A great example to illustrate this is the freezing point curve[1] of sulphuric acid (see Fig. 3), there are multiple sharp inflection points on the freezing point curve as the acid strength changes from 0 to 100 wt-% H_2SO_4. As the strength

Fig. 4: **Changes in specific density of sulphuric acid/oleum relative to acid concentration**[2]



of the acid changes the liquid changes from a fully hydrolysed (aqueous) state to various hydrates such as tetrahydrate (H_2SO_4-$4H_2O$), hemihexahydrate (H_2SO_4-6½ H_2O) and octahydrate (H_2SO_4-$8H_2O$).

Chemetics simulation and modelling

Chemetics started to develop "in-house" process simulator programs using spreadsheets and programming languages such as Fortran and Basic back in the 1980s. Currently Chemetics uses both in-house proprietary plant simulators as well as commercially available process simulators software to fulfill the needs of plant operators.

Customisation of physical properties

Sulphuric acid and oleum have properties that are highly non-linear with concentration, as an example the density increases

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Table 1: **Summary of scenarios**

Key observation accounted for?	Scenario					
	Bed 4 catalyst	CHX leak	CRHX leak	HHX	IRHX	CHX + CRHX
Emissions	yes	yes	yes	no	yes	yes
ΔSO_2 across CHX	no	yes	no	no	no	yes
SO_3 after CRHX	no	no	yes	no	no	yes
SO_3 after IRHX	no	no	yes	no	yes	yes
Likelihood (based on condition)	low (mostly new)	high	high	certain	unknown (not inspected)	high

Source: Chemetics

with increasing concentration, but essentially levels off above ~93%, and then actually decreases slightly by 100%. In the oleum range the density increases again, with a much steeper slope than in the acid range. This effect is summarised in Fig. 4[2]. Changes in direction or discontinuities in slope of the property values cause errors when using standard property packages.

Chemetics uses several different customised property sets for sulphuric acid at various concentration ranges to accurately calculate physical property relationships. Chemetics has done extensive customisation of physical properties specific to the sulphuric acid industry to address these issues[3]. Two examples where Chemetics has used simulator models for troubleshooting and debottlenecking are given below[4]:

Troubleshooting in a regen sulphuric acid plant

A regeneration sulphuric acid plant was suffering from slowly worsening SO_2 emissions. Repairs had already been attempted on the hot heat exchanger; however, the emissions were still getting worse to the point of forcing production rate reductions.

The site was limited in access to some sampling locations and to the accuracy of the measured temperatures, concentrations and flows due to the age of the instruments. The site data did not provide a clear cause for the performance issues so a modelling study was initiated to help determine the cause of the performance issue.

To execute the modelling study models were prepared with different plausible failures. Examples of these models are leaks in each gas exchanger or degraded catalyst in certain beds. The models were adjusted to match the observed plant data as closely as possible. Each model was then compared with the whole set of plant data, gas sampling results, and other observations to determine which failure scenarios could account for the specific differences seen in the plant vs the baseline flow sheet performance.

The results indicated a major leak on the cold reheat gas exchanger and a minor leak in the cold exchanger. The plant can use this to prepare repair and replacement plans prior to the next turnaround and avoid costly additional downtime. An additional benefit of developing this plant model was that it becomes a tool for the operators to determine the optimal operating parameters to maintain acceptable emissions while the long term repair plans are being prepared and executed.

Debottlenecking a metallurgical acid plant

A metallurgical sulphuric acid plant utilises parallel tail gas reheat exchangers (TGR exchangers) made out of carbon steel to partially cool the SO_3 gas entering the absorption tower and to reheat the tail gas (unabsorbed gas from the absorption tower) going to the plant stack. When the existing twin gas exchangers reach the end of their services lives, a study was performed to determine if a single new high efficiency TGR Exchanger could replace both the existing TGR Exchangers while addressing the need for a SO_3 Cooler.

Using process simulators with validated data from plant operations, the plant model confirms that it is possible to replace the existing low efficiency carbon steel exchangers with a single radial flow, high efficiency stainless steel TGR (Fig. 5).

This finding provides tremendous value to the client as it eliminated the need for a new SO_3 cooler fan installation and associated equipment, thereby significantly reducing capital and operating costs. In addition, this has the added benefit of simplifying the control system used to regulate acid plant temperatures. With the use of a low pressure drop, radial flow stainless steel tube design, it eliminated the need for future (and expensive) re-tubing of the existing carbon steel TGR exchangers.

PHOTOS: CHEMETICS

Fig. 5: Chemetics radial flow tail gas reheater installed. Unit process design developed by creating a model of current plant operation and optimizing the unit to achieve desired plant performance.

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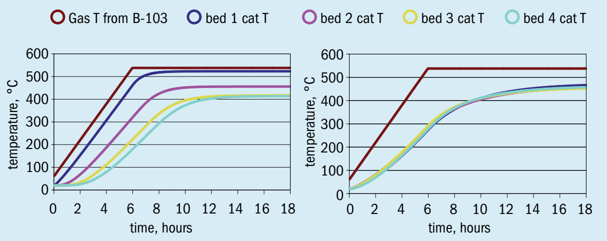
Fig. 6: **NORAM dynamic simulation of converter preheating. Left: Catalyst heat-up curves with 100% of the hot gas fed to bed 1. Right: Catalyst heat-up curves with heating of all four beds simultaneously.**



Source: NORAM

NORAM Engineering simulator models

NORAM Engineering specialises in the design and debottlenecking of sulphur-burning, acid regeneration and metallurgical sulphuric acid plants and equipment and uses sulphuric acid plant simulation to investigate, diagnose and optimise the sulphuric acid plant[5] (see *Sulphur* No. 359, pp. 43-45). Some examples of applications where NORAM has used simulator models are given below[6].

Flowsheeting complete plants

NORAM's proprietary heat and mass balance routines for sulphuric acid systems are effectively used to simulate a variety of plant systems. Accurate prediction of performance and physical properties allow for the complete understanding of the plant unit operations and system integration.

Catalyst preheating system

The plant preheating system was re-engineered, specifically to improve the preheating of the catalytic converter. The capacity of the preheater was reviewed, and hot gas lines were directed to each of the catalyst beds to ensure adequate preheating is achieved in all parts of the converter. The equipment was designed and a dynamic simulation was developed to identify the improvements obtained.

Based on the results of the simulation (Fig. 6), it was concluded that for the existing design, if all the hot gas from the preheater is fed to bed no.1 only, achieving a catalyst temperature of 800°F (427°C) is not possible for beds 3 and 4.

For the new design where all four beds are preheated simultaneously, all four beds heat-up evenly, and reach 800+°F in approximately ten hours. The required hot preheat gas flow distribution between converter beds is as follows: 24.0% to bed 1; 30.4% to bed 2; 32.7% to bed 3; 12.9% to bed 4.

The simulation shows how the plant can be heated-up faster to the target temperatures. This also provides flexibility in case the client prefers to increase the heat-up rate of a certain bed. Tight shut-off valves and spectacle blinds are provided to get back to the original design conditions (The four preheater isolation valves are triple offset high-temperature valves). The increase in bed temperature after preheating (for beds 2, 3 and 4) provides higher margin over the sulphuric acid dew point and reduces the chances of acid condensation, corrosion and fouling.

Design of inter-bed gas mixing device

In this case, a plant utilised a cold air quench in between beds 3 and 4 to cool the process gas. NORAM modified the mixing strategy to simplify the equipment design. NORAM developed computational fluid dynamics (CFD) models to design an adequate gas mixing device. This is important to ensure that the inlet gas to bed 4 has a uniform temperature, and uniform O_2 and SO_2 concentration. This design allows for adequate conversion of SO_2 and is important during start-up as well as normal operation.

ANSYS Software R15.0 was utilised to carry out the CFD simulations. The fluid is modelled as 3-Dimensional, non-isothermal flow. The following parameters are evaluated for each CFD case to identify the best inter-bed quench system design:

- Inlet temperature to converter bed 4 (uniform temperature is preferred).
- Inlet gas velocity to converter bed 4 (uniform velocity is preferred).
- Process gas pressure drop (low pressure drop is preferred).
- Inlet concentration profile of O_2 and SO_2 to converter bed (uniform concentrations are preferred).
- Overall conversion of converter bed (maximum conversion is preferred).

Fig. 7 shows the CFD results. The performance of the existing design was compared against the new design:

Existing design

The simulation results of the bed temperature above converter bed 4 for the existing design are shown in Fig. 4 (left). It is clear that the gas mixing for this geometry is not complete.

For this reason, the temperature above bed 4 is not uniform and varies from 752 to 866°F (400 to 463°C). The deviation in gas temperature was 114°F (63°C). In this case the conversion of bed 4 would be affected due to the variation in temperature.

New design

The gas streamlines and the bed temperature above bed 4 are shown in Fig. 7 (right). In this case, the temperature above bed 4 is much more uniform. The temperature varies between 826 and 840°F (441 to 449°C). It is important to note that the target temperature (as per NORAM's converter design) for this particular bed is 832°F (444°C). All parts of bed 4 would receive gas within 10°F (5°C) of the target temperature.

Catalyst evaluation

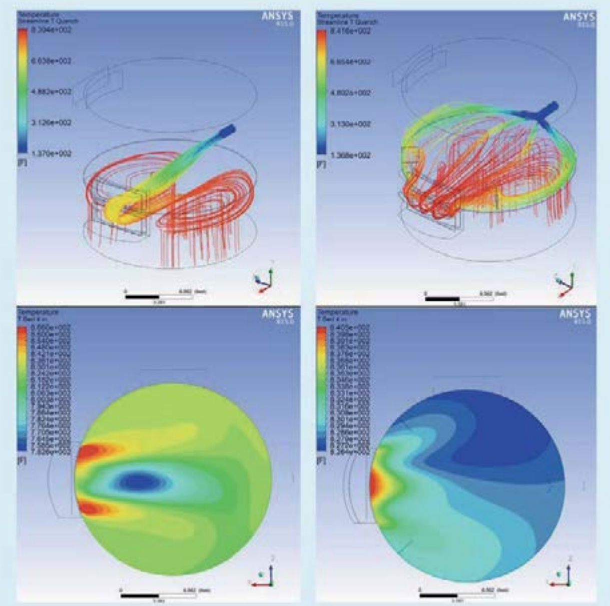
In this case a client asked NORAM to review the technical and commercial quotations from three major catalyst vendors. Best efforts were made to ensure that all vendors worked using the same assumptions to be able to make a balanced assessment of the different proposals.

A technical evaluation was made based on the following performance indicators:

- conversion per bed;
- outlet temperature per bed;
- pressure drop per bed (gives pressure drop estimate of grids and ceramics separately);
- emissions in ppm.

A commercial evaluation was made based on the following:

Fig. 7: **NORAM CFD simulation for gas mixing. Left: Existing design. Right: Upgraded design. See numeric values on left side of each plot for temperature predictions**



Source: NORAM

- catalyst price;
- two year warranty on conversion;
- pressure drop warranty at start-up and after six months;
- cost of blower power required to overcome the catalyst pressure drop over a period of ten years.

It was found that the catalyst with the highest conversion, and the lowest operating pressure drop had the lowest cost to the client over a period of ten years (on a net present value basis). It was noted that pressure drop was an important factor in the comparison of the three proposals. The final selection, purchase and installation of the catalyst was made by the client, and they decided to source the catalyst from a vendor based on other considerations.

Dynamic simulations for gas temperature control

NORAM developed a dynamic simulator using Aspen Dynamics software to confirm the operability of the gas temperature controllers. Based on the dynamic simulations, specific recommendations were given to implement automatic temperature control for converter beds 3 and 4. The controlled variable is the bed inlet temperature at the top of the catalyst for each bed. The auxiliary quench air blower discharge pressure and vent to atmosphere can be kept on manual control for periodic adjustment.

Operator training

Operating, maintaining and upgrading a sulphuric acid plant is a challenging task. It requires knowledge about many disciplines that is difficult to convey to newcomers to the industry. In addition, experience from senior engineers and operators is difficult to transfer within an organisation. NORAM offers a systematic training course that utilises knowledge management techniques to train managers, engineers and operators based on the core knowledge already existing within the plant personnel, and enhanced by state-of-the art know-how on sulphuric acid manufacturing, including the presentation of simulation results.

Topsoe simulation of the sulphuric acid converter

Capable software for acid plant simulation is a crucial tool to be able to fully understand the behaviour of the plant at specific conditions, and to predict how well new concepts, such as new layouts or catalyst solutions will perform.

Over the past decades, the design of converter catalyst loading in a sulphuric acid plant has evolved from simple rules of thumb, via simple computer simulations and basic models, to the advanced models available today[7] (see Fig. 8).

The capabilities of different parties to predict the response of the converter will differ, as will the need. A plant manager or plant engineer will typically have some rules of thumb they use to assess performance of the converter, while most catalyst vendors and engineering companies will have computer models that offer more detailed insight into how to the converter will behave at different conditions. The more advanced the models that are available, the better the predictions and the more detailed predictions can be made, especially at conditions that are further from "standard". The extra detail can be utilised to optimise the plant further or even to evaluate new plant configurations.

Understanding the effect of catalyst beds

Industrial sulphuric acid plants often only have converter temperature measurements and rarely have the possibility to regularly measure gas concentrations on the inlet and outlet of each bed. In the few cases where temperature measurements are available in the beds, the exact catalyst height above that measurement is often unknown. Needless to say, the temperature and conversion profiles down through the converter catalyst beds are unknown to the operator of the plant, who can only assess performance based on the outlet temperatures. Using computer models, however, allows the temperature and conversion trends to be followed in great detail. The models can be employed to assess the effect of low activity catalyst, or to see how best to employ caesium catalyst.

Effect of low temperature activity

Written as a chemical reaction, the catalyst oxidation of SO_2 to SO_3 looks rather simple;

$$SO_{2(g)} + \tfrac{1}{2}\, O_{2(g)} \rightleftharpoons SO_{3(g)}$$

$$\Delta H° \approx -94 \text{ MJ/kg-mole}$$

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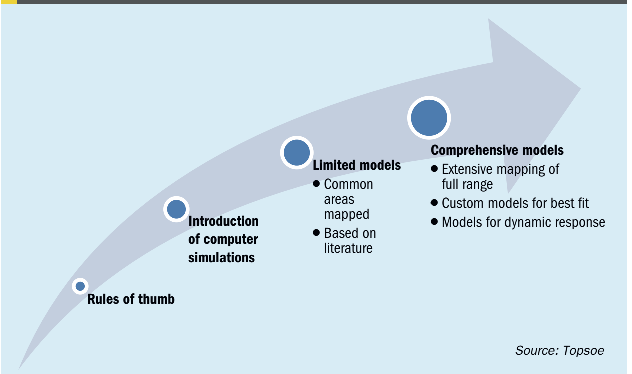
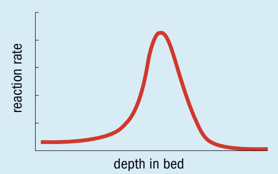
Fig. 8: **Development within SO_2 converter predictions**



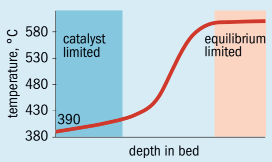
Source: Topsoe

Fig. 9: **Reaction rate, 10% SO_2, 11% O_2, inlet temp. 390°C**



Source: Topsoe

Fig. 10: **Limitation in a catalyst bed, temperature profile**



Source: Topsoe

However, trying to optimise it for various gas conditions, inlet temperatures and catalyst activities is no simple matter.

The reaction is exothermic, which means that the equilibrium will be pushed in favour of SO_3 formation, if the temperature is decreased. On the other hand, the rate of reaction will increase if the inlet temperature is increased, hence inlet temperature becomes a balance between striving for higher conversion at the bed outlet and maintaining sufficient reaction rate in the top part of the bed.

A typical reaction rate through a catalyst bed is illustrated in Fig. 9, where the first part of the curve shows a slow start with a very low reaction rate, and thus very low temperature increase, corresponding to minor SO_2 oxidation to SO_3, until it reaches a certain point where the reaction rate increase rapidly. After reaching the maximum reaction rate, the reaction rate is decreased again due to the increasing contribution of the reverse reaction

$$SO_{2(g)} + ½ O_{2(g)} \leftarrow SO_{3(g)}$$

as high SO_3 concentration and high temperature bring the reaction close to equilibrium.

The limitations at the bottom and top of the bed are not the same, the low reaction rate in the beginning of the bed is limited by the efficiency of the catalyst at the given inlet conditions, in particular temperature. The reaction simply does not start fast enough, due to too low inlet temperature and/or insufficient catalytic activity. In this region catalyst activity is exceptionally important. Installation of even a small amount of good fresh catalyst or high performance caesium catalyst in this crucial region will significantly boost ignition capability and overall performance of the entire bed. In the last part of the catalyst bed, the reaction rate is limited by the equilibrium of the conversion reaction.

A typical temperature profile through a catalyst bed is illustrated in Fig. 10, which also illustrates in which temperature ranges the reaction rate is limited.

Fig. 11 shows the temperature profile when operating at an inlet temperature of both 390°C and 420°C. The curves illustrate very well the effect of increasing the inlet temperature, the reaction initiates much faster and less catalyst is needed to bring the reaction close to equilibrium.

One consequence of the increased inlet temperature is, however, lower maximum conversion due to lower equilibrium conversion, which is not usually desirable.

Effect of catalyst deactivation

Simulation models can also be used to obtain a better understanding of how deactivation of the catalyst will affect conversion, and how it can be countered.

The performance of a full bed loaded with old or inferior catalyst is presented together with the reference loading in Fig. 12. At the lower inlet temperature the inferior catalyst is unable to achieve the required conversion rate due to a dramatic reduction of ignition capability. The consequence of the low reaction rate is that the main part of the catalyst bed is utilised to achieve a temperature where the reaction ignites. The graph also shows that increasing the inlet temperature can provide a solution to the problem, as even the inferior catalyst is sufficient to reach equilibrium. The higher inlet temperature comes at a cost of lower total bed conversion.

Fig. 12 also shows the importance of installing good fresh make-up catalyst in the top of the bed after screening. Installation of low activity catalyst will result in little, no, or potentially even negative impact on bed performance, since the catalyst is installed in the most crucial location where catalyst activity and low temperature performance has the highest impact on reaction rate.

Effect of Cs-promoted catalyst

Another way to overcome low temperature limitation is by installing caesium-promoted catalyst in the catalyst bed, the same arguments as used above apply to the use of caesium promoted catalyst. It is again important to select a catalyst with a good low temperature activity to counter the low temperature limitations in the first part of the bed.

The effect of installing a top-layer of caesium-promoted catalyst is well illustrated in Fig. 13, where the reaction rate increases faster and reaches the same high reaction rate earlier in the bed. The outcome is that it is possible to maintain the same conversion rate with a lower catalyst volume installed.

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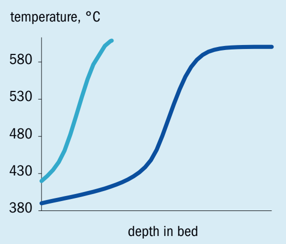
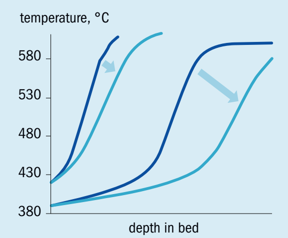
Fig. 11: **Effect of increasing the inlet temperature from 390°C to 420°C**



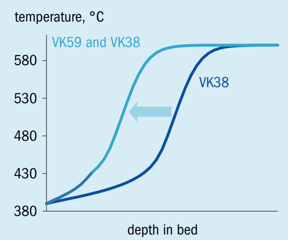
Source: Topsoe

Fig. 12: **Effect of ageing and inferior catalyst**



Source: Topsoe

Fig. 13: **Effect of a top layer of Cs-promoted catalyst**



Source: Topsoe

Revealing plant limitations through plant simulations

Robust plant simulations allow fast evaluation of how a new plant concept or catalyst loading would perform. It can also help understanding the effect of different feed gas conditions overall SO_2 conversion and plant operability. For example, Fig. 14 illustrates how single absorption, double absorption and triple absorption performs with the same gas conditions and catalyst loading.

Simulation models are also very useful in determining the necessary catalyst loading when designing for different gas compositions (see Fig. 15).

As indicated in Fig. 15, the changes in the catalyst loading necessary to achieve a fixed conversion requirement changes considerably as the gas composition changes.

Due to the vast number of different combinations imaginable, and the varying requirements between different beds, it is all but impossible to capture this through design guidelines alone. Good simulation models are necessary to ensure both cost effective and reliable catalyst loadings or plant design.

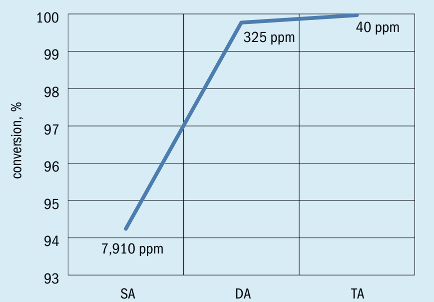
Transient simulations

During steady state, or near steady state, conditions, a well maintained sulphuric acid plant with a state of the art catalyst loading in the converter can achieve very low SO_2 emission levels. Under transient conditions, however, the same low emission levels cannot easily be achieved. During start-up, shutdown, feed change, and process upsets, unfavourable operating conditions of the plant typically lead to increased emissions. These emissions are attracting more attention from regulatory authorities and proactive plant owners, and some plants have regulatory emission limit requirements during the start-up period. The general challenge for plant operators is to shut down and start up as fast as possible with a minimum fuel consumption and with minimum SO_2 and acid mist emissions.

The dynamic behaviour of the catalytic converter is of major importance in these situations. Firstly, the sulphuric acid catalyst requires certain minimum temperatures to oxidise SO_2 efficiently to SO_3. Secondly, the catalyst has a significant absorption capacity for sulphur oxides, which must be taken into account as it affects heat evolution and SO_2 conversion during transient operation.

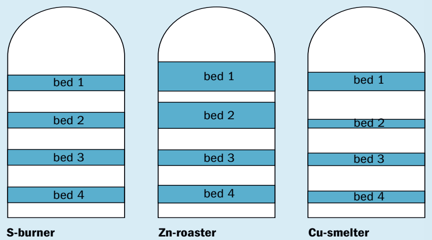
Due to the risks involved, both to the environment and people in or close to the plant, experimenting with different new concepts for handling these conditions is often not practically possible. However, simulation models allow new concepts to be tried, without any risk to the surroundings, or being forced to stop the start-up process. Also important is the ability of the simulation models to quickly show the effect of different process settings. Getting the same data from real life tests might take multiple trials, and as with all real life testing, the conclusions would likely be less clear due to process variations.

Fig. 14: **Simulated conversion and emission of three different plant configurations**



Source: Topsoe

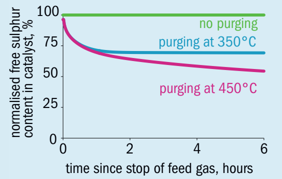
Fig. 15: **Relative catalyst loading required to achieve 99.9% conversion at three different gas conditions**



	S-burner	Zn-roaster	Cu-smelter
Gas (SO_2/O_2)	10.5/10.5	7.0/9.0	15.0/13.9
Relative loading	100%	133%	80%
Emission	125 ppm	80 ppm	195 ppm
Production	1,000 t/d	1,000 t/d	1,000 t/d

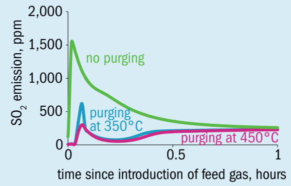
Source: Topsoe

Fig. 16: **Effect of purge time and temp. on catalyst sulphur content**



Source: Topsoe

Fig. 17: **Effect of temperature on start-up emission**



Source: Topsoe

Effect of purging

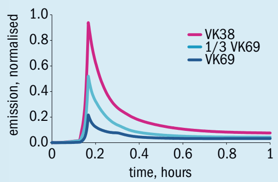
As a result of the ability of the sulphuric acid catalyst to absorb or desorb SOx, the way the catalyst is purged during shutdown will have a profound effect on SO_2 and SO_3 emission when the plant is started back up. A well purged catalyst bed will reduce issues with desorption of SO_3 during start-up, and have a significant SOx absorption capacity which will reduce the emission peak often seen during start-up. The temperature of the catalyst during the purge is crucial for desorption of SOx from the catalyst because it affects both the rate of desorption and minimum the degree of sulphatisation achievable for the catalyst. Fig. 16 shows the effect of different temperatures and purging time on the catalyst sulphur content, while Fig. 17 shows how the different purge temperatures affect the emission during the subsequent start-up.

From Figs 16 and 17 it is apparent that there is much to gain in terms of reduced start-up emissions by spending some more time and money on a longer or warmer purge of the catalyst when shutting down. What is achievable in practice is of course plant specific, but even a smaller improvement may be what it takes to get the emission peak below the limit.

Effect of Cs-promoted catalyst on start-up

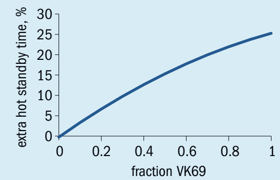
For practical reasons, purging warmer or longer during shutdown is not always an option. It has long been known that caesium catalyst has an effect on start-up SO_2 emissions. How big the effect is, and its effect at the specific plant or condition, however, is not known. With dynamic simulation models, this can be investigated. In

Fig. 18: **Effect on start-up SO_2 emission of using caesium catalyst (VK69) in Bed 4**



Source: Topsoe

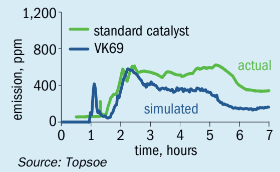
Fig. 19: **Hot standby time permissible with differential loadings**



Source: Topsoe

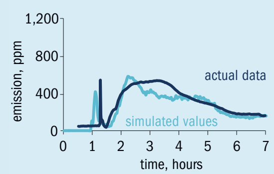
Fig. 20: **Industrial start-up data using standard catalyst compared to start-up performance using VK69***

*Showing similar performance, despite using a total of 30°C lower bed temperature for beds 3 and 4.



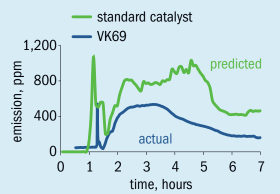
Source: Topsoe

Fig. 21: **Simulated and industrial start-up data with VK69 in the final bed showing good agreement between the two**



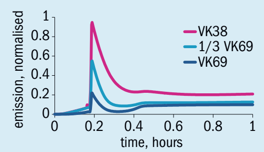
Source: Topsoe

Fig. 22: **Predicted start-up emission when using standard catalyst compared to actual emission when using caesium catalyst in the final bed**



Source: Topsoe

Fig. 23: **Effect on the start-up SO_2 emission of using caesium catalyst (VK69) in bed 4***



* When the catalyst has been purged at 450°C for 30 min during shutdown.

Source: Topsoe

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Fig. 18, the effect on the emission peak of using one-third of a bed or a full bed of caesium promoted catalyst (VK69) in bed 4 is shown when starting up after each bed has cooled down 60°C.

It turns out that for this 3+1 DA plant, the emission during start-up cat be cut by half by replacing one third of bed 4 with VK69 and by 75% when using a full bed.

If the current emission is not an issue, but rather the time the plant can be allowed to cool off or the time available to heat the plant during start-up, using a caesium catalyst may also be a good solution. Fig. 19 shows the relative time a theoretical 3+1 DA plant can be allowed to cool down with different loadings.

From Fig. 12 it can be seen that a third of a bed of caesium catalyst in bed 4 of a 3+1 DA plant can compensate for 10% longer cool down and that a full bed of caesium catalyst can compensate for a 25% longer cool down with no increase in emission. This improvement in start-up performance of the plant is in addition to the improvement in steady state conversion, which in most cases is the main reason for adding a caesium layer in the final bed.

In the case of a running industrial plant, simulations indicate that the extra activity of the caesium catalyst could compensate for a total reduction in inlet temperature to the two last beds of 30°C, 20°C in bed 4 and 10°C in bed 3. The emission peak using the caesium catalyst and lower inlet temperatures is the same as before, but the average emission during the complete start-up period is lower, see Fig. 20.

After the caesium catalyst has been installed, the emission with the lower inlet temperatures turns out to be very similar to that predicted, albeit with somewhat broader peak (see Fig. 21).

Finally, the dynamic models can be used to predict what the start-up emission would have been, if the same inlet temperatures had been used with the standard catalyst. In Fig. 22, the predicted start-up emission using standard catalyst is compared with the recorded emission when using caesium catalyst. The emission when using the standard catalyst is around twice as high compared to when caesium catalyst is used.

Maximising start-up performance

Simulations show that the positive effects of hot purging during shutdown does not nullify the effect of installing caesium promoted catalyst in the final pass, but the two effects can be combined for even greater SO_2 emission reduction during start-up. Fig. 23 shows the effect of using different catalyst loadings in bed 4 when also having purged the catalyst at 450°C for 30 minutes during shutdown.

Figs 18 and 23 are very similar in appearance, meaning that the relative improvement of using a caesium catalyst in bed 4 is similar regardless if the catalyst has been purged hot or cold during the shutdown. It is however important to remember that the peak for the standard catalyst is far lower in Fig. 23 than in Fig. 18, compare the curves for 450°C purge and no purge in Fig. 17.

Outotec smart digital applications

Outotec has in recent years intensified its effort in developing models to accommodate the increasing customer needs for simulation based offerings[10].

Besides using simulations to support process development, plant design, equipment design, etc., simulations nowadays form the basis to improve plant operational safety as well as to achieve increased operational performance. These efforts apply not only to the sulphuric acid plant, but also to the gas cleaning and upstream metallurgical process. For a fully digital supported plant operation, Outotec is also developing in-house process plant training simulators, ensuring high quality operator training.

Outotec's simulation philosophy comprises three smart layers of process know-how: smart equipment, smart process and smart site. Outotec is applying simulations to these layers, ensuring increased plant safety, optimised plant operation and up-to-date training methods at customer sulphuric acid sites.

Outotec has identified three main levels for simulation applications:

- Equipment level
- Process level
- Site level

In another dimension, two different cases for simulations can be identified:

- Design and engineering, using simulations to enhance quality of product design
- Operation and commissioning support, where simulations play an essential role

This classification structure is illustrated in Fig. 24. On the left side, design and engineering approaches are illustrated, categorised with respect to equipment, process and site level. Giving one example, Outotec's enhanced process simulation capabilities as well as detailed information on heat transfer and heat recovery have led to the development of the HEROS® system, a proprietary process module used in modern sulphuric acid plants to increase heat recovery[11]. Consideration of the advanced levels of simulation based process and site design, it is typical to simulate several discreet, but interdependent, plants in combination, up to a full site assessment. In doing so, correct dimensioning of several process steps ensures combination of all plant sec-

Fig. 24: **Outotec simulation models are used at different levels in design process as well as in various digital operational support systems**

	***Smart* design & engineering**	**Operation & commissioning**
EQUIPMENT	**Proprietary equipment design** ● Detailed design tools and simulation for equipment dimensioning ● Example: Converter tower, HEROS®	***Smart* equipment** ● Health grade assessment of equipment ● Example: PORS ● Advanced control
PROCESS	**Process simulation** ● Heat and mass balance ● Flowchart, e.g. HSC ● Development, design & dimensioning	***Smart* process** ● Process advisor, monitoring & optimisation ● Training simulator ● Outotec Pretium products
SITE	**Site simulation** ● Full site flowchart	***Smart* site** ● Multiple plant optimisation systems ● Outotec Pretium products ● Manufacturing execution systems

Source: Outotec

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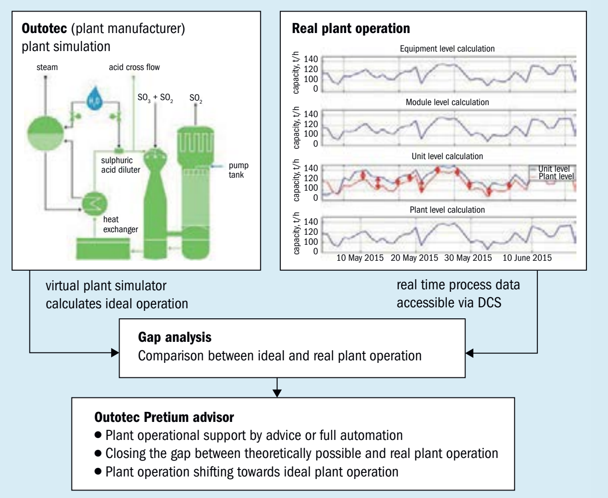
tions at site working together as intended. Applying smart design and engineering processes using simulation prevents oversized as well as undersized equipment or plants and thus allows Outotec delivery of up-to-date plants without bottlenecks.

On the right side of the diagram, simulation methods play an important role in digital supported equipment, processes or sites. Smart equipment uses detailed simulation models on unit equipment, making such equipment or process units intelligent. As an example, Outotec has introduced the Plant Operability Reliability and Safety (PORS) system for sulphuric acid plants[11]. A good example of this is the use of PORS on the product acid cooler, where mathematical models monitor the heat transfer between acid and water side in order to allow an early leakage detection. Such simulation models integrate a deep process understanding, as well as detailed equipment knowhow. The equipment gains a certain degree of intelligence and connectivity and thus is considered smart equipment. Furthermore, smart equipment can include advanced control algorithms to ensure operational stability and enhance equipment performance.

Outotec's smart processes are more extensive and may well be a combination of a number of pieces of smart equipment. Smart processes comprise Outotec Pretium products, covering plant wide process advisor systems, monitoring and optimisation functionality[12]. Outotec Pretium is a proprietary platform for development and implementation of digital products[13]. Therein, simulations can form the basis for operational advice. Such advice is presented to the operators, which can improve the plant performance or reduce emission levels[14, 15]. Also on the process level, Outotec uses dynamic training simulators to train personnel who will ultimately operate the plants. Such training simulators are based on dynamic process simulations. In contrast to the steady state high fidelity process simulations used for process design, dynamic simulation models utilise simplifications where required. However, such simulations are fully capable of reproducing transient plant performance and simulating the plant response to operator inputs. The dynamic training solutions include the process control loops and thus allow new operators to train without risking the production process. Furthermore, trainees can gain experience with fluctuating process conditions, feed/blend variations

Fig. 25: **Gap analysis between plant simulation and measured plant data in real time**



Source: Outotec

or even with defective equipment. The process integrity can thus be increased by using Outotec training solutions.

On the level of smart sites, Outotec is combining different features of both smart equipment and processes over the traditional battery limits of single plants. Logically, optimisation of a process plant network can result in significant advantage over individually optimised operations.

Comparing such future plant concepts with classic plant operation, significantly more measured process values are utilised in the production process and evaluated automatically and in real time than at most production sites today. Process plants are generally handled by human operators, who can only follow a certain number of trends or a limited quantity of information. Operating a plant with full digital support allows for automated monitoring and supervision of all measured information[16]. In the following sections, operational case studies of smart digital applications within Outotec plants are given.

Outotec PORS-System

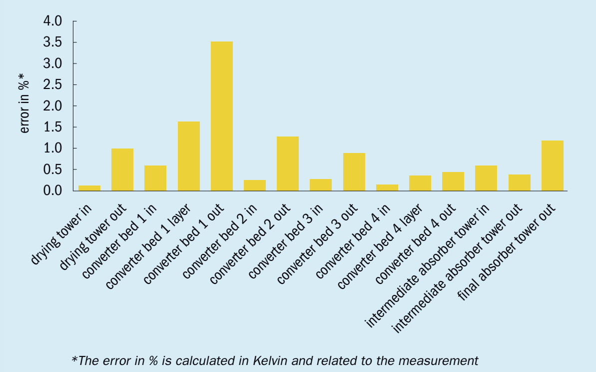
Outotec's PORS system is a state-of-the-art monitoring and supervisory system. It is based on simulation models and mathematical calculations and detects both short term process failures and long term deviation trends. PORS was developed to guide and support plant operating personnel. The system enhances situation awareness in case of potential operational problems and challenges and thus allows a safer and more efficient handling of the process[11].

What started as a safety related system associated with heat recovery is currently being extended to a full plant operational simulation based support system, including the gas cleaning and acid plant as well as upstream metallurgical process steps such as the roasting plant.

The scheme of a gap analysis within the PORS-System is detailed in Fig. 25. Outotec as process plant supplier has all relevant equipment and process simulation models as well as the experience in relation to the material characteristics, long-term process behaviour or conversion rates of catalytic reactions from SO_2 to SO_3, etc.

The full simulation model results of process plant or plant site are compared to the current readings from the distributed control system (DCS). On the simulation side, the theoretical plant operation is available, whilst the DCS measurements show the current real time situation of the process plant. A gap analysis compares the ideal or theoretical operation with the real time data and reveals where the process operation or operating conditions are

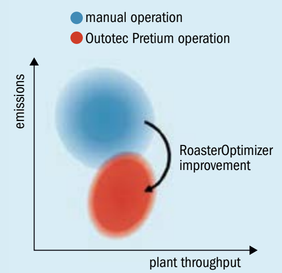
Fig. 26: **Simulation accuracy for sulphuric acid flowchart simulation**



**The error in % is calculated in Kelvin and related to the measurement*

Source: Outotec

Fig. 27: **RoasterOptimizer – expected long term reduction of emissions**



Source: Outotec

not as expected. Such gaps can now be used in a number of different ways.

If an operational issue is detected, advice can be given to the operators in the form of precise information of which setpoint should be changed in order to bring the plant operation closer to the theoretical optimum. Optionally, such setpoints can be set automatically. Thus, the gap between theoretical and real plant operation is minimised. The operation is thus improved, targeting the theoretically possible operation calculated by Outotec's mathematical simulations.

Gaps can also be caused by fouling effects. Sulphuric acid plants have multiple heat exchangers of different types. The precision of mathematical models of heat exchangers is usually very high, however variances between simulated and measured heat exchange can be for different reasons. For example, sudden rises in the gap between theory and measurements are usually a sign of leakage, whilst long term monitoring also allows for the detection of fouling trends.

Simulation accuracy

In order to achieve the required simulation accuracy required for both fault detection algorithms as well as for operational support, various experts within Outotec are involved. Process experts are responsible for bringing in process knowhow, flowsheet calculations, as well as plant wide calculation models and site experience. Equipment experts provide the required detailed knowhow on single process units and catalyst experts ensure the accuracy of detailed models regarding the chemical conversion from SO_2 to SO_3 and H_2SO_4.

The simulation accuracy for temperatures in a sulphuric acid plant flowsheet simulation is shown in Fig. 26. Therein, simulation results and plant measurements are compared. The error is given in % and is calculated by

$$e=\left|\frac{(\gamma_{sim}-\gamma_{measured})}{\gamma_{measured}}\right|\cdot 100$$

γ_{sim} is the respective simulated temperature value in K, while $\gamma_{measured}$ is the respective measurement value in K, captured by the DCS. The DCS measurements are mean values over a certain time range. In summary, the accuracy of the simulation is very high with most values below 1% error. However, the first converter stage outflow temperature shows deviations between measurement and simulation of more than 3%, thus requires further investigation. Such an error can either mean that the model parameters are inaccurate or that the catalytic converter in the first stage shows effects of aging.

Advanced automation

In addition to the simulation-based fault detection methods and operational support functions for the acid plant, Outotec has recently strongly intensified its effort in advanced control and automated optimisation methods for whole plant units. With respect to a sulphuric acid and gas cleaning plant train, a strong improvement of the operational stability was achieved by applying a fully automated control and optimisation scheme to the upstream metallurgical roasting plant. Today, several customers operate their roaster with Outotec's RoasterOptimizer, benefitting from increased throughput whilst maintaining product quality at a high level.

The RoasterOptimizer is a multivariable control and optimisation system, combining detailed simulation models with advanced automation concepts to enhance the roaster operation. Besides monitoring various variables of the roasting plant, the system also considers process variables of the downstream gas cleaning and acid plant. One of the results of implementing the RoasterOptimizer for the complete process chain has been security in ensuring that environmental emission values were not exceeded whilst increasing plant capacity. Fig. 27 indicates expected long-term results for environmental factors when the plant is in operation using the RoasterOptimizer, clearly demonstrating the advantage in terms of reduced emissions.

Table 2 shows operational effects and benefits that can be measured over several months of operation.

A combination of digital tools for upstream metallurgical process steps (e.g. feed preparation and roasting), as well as downstream process steps (e.g. gas cleaning, sulphuric acid production and hydrometallurgical plant sections), reveals the full potential in the operation of today's production sites. In the given example, the

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Table 2: **RoasterOptimizer benefits**

Feed material preparation with increased blend flexibility	→	addition of waste streams and/or low grade concentrates, lowering production cost
Roaster plant availability and capacity increase	→	through process stabilisation, reduced stress on plant and equipment
Acid plant environmental improvements	→	lowering SO_2 emissions, reducing bottlenecks
Leaching efficiency increase	→	through higher calcine product quality, lowering production cost in hydrometallurgical plant section

Source: Outotec

integration between the RoasterOptimizer, stabilising and optimising the fluidised bed roaster, with PORS, monitoring and supervising the full acid production process, results in a combined optimisation of the full production chain of roasting – gas cleaning – sulphuric acid – leaching plant. This represents leading edge plant performance through simulation and digitalisation and is a significant step towards fully automated production processes, which can be expected in the future.

Dynamic training simulators

As described briefly above, a further typical field of application for simulations are training systems. Based on dynamic full plant simulations, such training systems allow trainees and operators to familiarise with the plant operation in a safe environment. Outotec utilises dynamic training simulators amongst others to train sulphuric acid plant operation and roaster plant operation. Considering the roaster dynamic training simulator as an example, the training system is used prior to the commissioning of a new plant. Thus, new operators that have no real experience with the roaster operation highly welcome the opportunity to train in a close to realistic environment. Familiarisation with typical process behaviour, but also with operational challenges (upset process conditions), occurs before the real plant is in operation. The trainees learn typical plant delay times and controller behaviour but also have the option to speed up the simulation (up to 50 times that of real time) to understand long term process reactions without a long waiting time. Further learning effects are related to variability of fuel source, challenges in relation to fluidised bed operation and solids handling, but also with respect to failure scenarios or how to handle plants with defective or worn-out equipment. Start-up and shut-down procedures can also be trained, giving current and future operators a full understanding of critical issues, such as heating rates. Outotec dynamic training simulators are configured so that the trainer can always playback stored training sessions to discuss operational failures or exceptionally good training performances. Customer feedback on dynamic training simulators are constantly positive, highly appreciating the opportunity to train personnel without operational risk.

Worldwide trend towards digitalisation

Besides roaster, gas cleaning and acid plants, Outotec's effort on digital operational plant support is currently intensifying on various processes. As an example, dynamic training simulators for waste-to-energy power plants are currently used for operator training prior to plant commissioning. Advanced control systems, optimisation systems as well as advisory solutions are used in various process technologies or are currently in a final development stage prior implementation for different process technologies.

The worldwide trend towards digitalisation and fully automated process plant operation can no longer be discounted and Outotec has already laid the foundation for future plant operations. The potential for a fully autonomous plant operation is just a matter of time and then operating companies can fully profit from the possibilities of digitalisation, after fully considering all the corporate implications therefrom. High availability, high throughput whilst maintaining product quality parameters as well as emissions and economically optimised plant operation will be the key future drivers. The proper use of detailed simulations for full flowcharts, dynamic plant simulations, equipment and plant detail simulations will form the basis for such a digital optimisation process. ■

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Combustion challenges in the reaction furnace

The overall performance of the modified Claus process is, for a large part, determined by the design and operation of the main burner and reaction furnace. In this article Duiker examines some important performance aspects of the reaction furnace; Siirtec Nigi reports on the benefits of its improved SRU thermal section; Blasch discusses its latest developments for SRU reaction furnace internals; and Jacobs introduces Temp-Protect, a useful tool for better temperature monitoring in the reaction furnace.

The desulphurisation of fossil fuels produces large amounts of hydrogen sulphide (H_2S) gas, which is mostly treated in the modified Claus process to recover elemental sulphur. In the thermal stage of the Claus process H_2S gas is partially combusted with air by a main burner, resulting in a flame with a temperature in the range of 900 to 1,400°C. The thermal stage is crucial to the overall performance of the modified Claus process, not only producing the majority of the sulphur but also ensuring the destruction of impurities (in cases where hydrocarbons or ammonia must be handled) and minimising undesirable by-products such as carbon disulphide (CS_2).

Mixing plays a significant role in all of these functions of the thermal stage, and high-intensity H_2S burners are especially effective in creating the conditions in the reaction furnace (RF) that ensure a proper functioning of the Claus process[1].

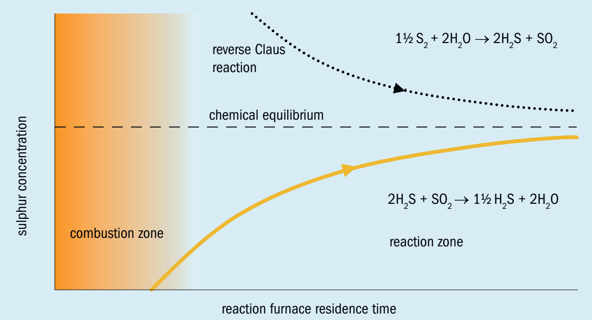
Sulphur recovery in the thermal stage

The classical way to represent the chemical conversion of H_2S to sulphur in the reaction furnace is by a two-step reaction mechanism: in the first step, oxygen reacts with one third of the H_2S feed to produce sulphur dioxide (SO_2) and, in the second step, the SO_2 reacts with the remaining two thirds of the H_2S to produce sulphur according to the Claus reaction.

$$H_2S + 1½O_2 \rightarrow SO_2 + H_2O \quad (1)$$
Combustion (step 1)

$$2H_2S + SO_2 = ½S_2 + 2H_2O \quad (2)$$
Claus reaction (step 2)

Fig. 1: **Sulphur concentration profile in the reaction furnace relative to equilibrium according to the classical two-step mechanism**



Source: Duiker

This mechanism predicts that, after the combustion stage (step 1), the sulphur concentration steadily rises until it approaches its equilibrium value in the Claus reaction (step 2), as shown in Fig. 1. In this scenario, mixing in the reaction furnace merely facilitates the combustion step and the approach to Claus equilibrium by bringing the reacting species together.

The RF chemistry is, in fact, much more complex than indicated above. Figs 2-5 illustrate some of the bulk chemistry taking place in the reaction furnace. The mixing and flow patterns induced by the high-intensity H_2S burners seem to affect the path that the chemistry takes in the reaction furnace. This is supported by field data[2] which show that significantly higher sulphur yields are obtained in the thermal stage of the Claus unit than would be predicted even by the equilibrium of the Claus reaction (2) at the observed furnace conditions. Detailed measurements of the gas compositions then indicate that the sulphur concentration in the reaction furnace approaches its equilibrium value from above (see Fig. 1), and not from below as would be the case if the chemistry in the reaction furnace follows the classical two-step mechanism described above.

An explanation for these observations is found in the special working principle of the high-intensity H_2S burner. Full-scale simulations of the burner/RF combination using techniques of computational fluid dynamics (CFD) in combination with detailed chemical reaction modelling show rapid, yet well-controlled mixing and simultaneous

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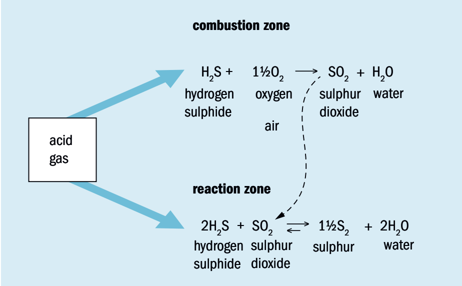
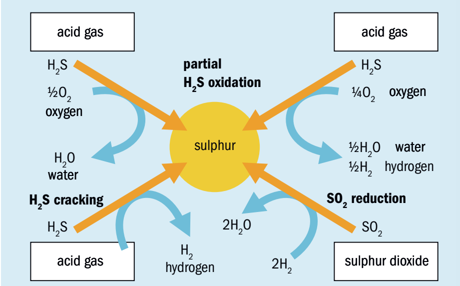
Fig. 2: **Sulphur formation in the reaction furnace**



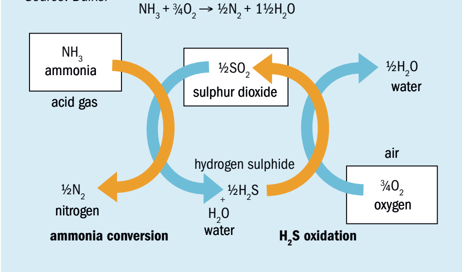
Source: Duiker

Fig. 3: **Additional paths to sulphur formation**



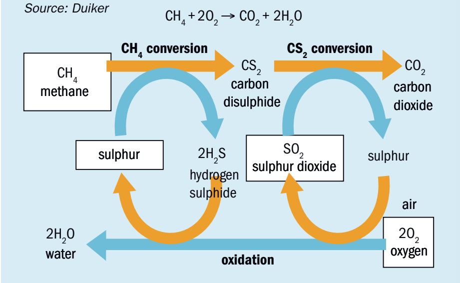
Source: Duiker

Fig. 4: **Ammonia destruction**



Source: Duiker

Fig. 5: **Hydrocarbon destruction**



Source: Duiker

reaction of H_2S with both the flue gases already present in the reaction furnace and the oxygen introduced into the combustion zone of the reaction furnace. Figs 6-9 show CFD models of the reaction furnace illustrating gas temperature, oxygen depletion, sulphur and SO_2 formation .

Sulphur formation in the reaction furnace

Chemical pathways are observed that lead to the partial oxidation of H_2S to sulphur in the combustion zone:

$$H_2S + ½O_2 \rightarrow ½S_2 + H_2O \quad (3)$$

$$H_2S + ¼O_2 \rightarrow ½S_2 + ¼H_2O + ¼H_2 \quad (4)$$

in addition to those leading to complete oxidation of H_2S to SO_2 as indicated by step 1 of the classical two-step mechanism (reaction 1). Significant sulphur generation is observed in specific parts of the combustion zone together with hydrogen (H_2) by thermal cracking of H_2S according to the reaction:

$$H_2S = ½S_2 + H_2 \quad (5)$$

which appears to be followed by further sulphur formation by the reduction of SO_2:

$$SO_2 + 2H_2 \rightarrow ½S_2 + 2H_2O \quad (6)$$

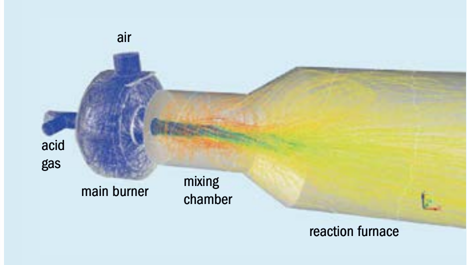
so that a peak in the sulphur concentration is observed after the combustion zone generated by the high-intensity burner.

At the RF outlet, sulphur concentrations are indeed found to exceed those at reaction equilibrium, indicating that the reverse Claus and H_2S cracking reactions are, in fact, taking place in the final (and more kinetically limited) sections of the furnace. Although the effect is less pronounced in Duiker's CFD simulations than suggested by its field observations, the sulphur concentration in the reaction furnace does seem to approach its equilibrium value from above as indicated in Fig. 1, and sulphur yields in the thermal stage are thus found to exceed the presumed maximum sulphur yields given by the equilibrium conditions of the Claus reaction (2). More importantly, however, it is observed that the mixing as induced by the high-intensity burners is capable of affecting the course of the chemistry in the reaction furnace, which may also be crucial factor in other aspects of the RF performance.

Impurity destruction: hydrocarbons and ammonia

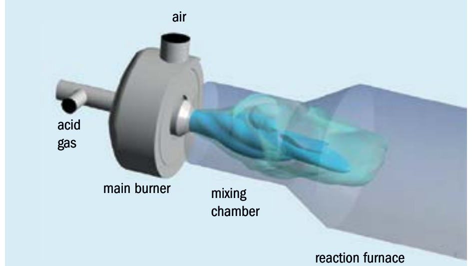
Another important function of the thermal stage of the modified Claus process is to effectively destroy impurities like hydrocarbons and ammonia (NH_3) present in the H_2S gas. As reported by Sulphur Experts[3], even very small levels of these compounds breaking through to the reaction furnace effluent can cause severe problems in the downstream process stages: in the case of hydrocarbons, rapid deactivation of the catalyst beds by carbon deposition and, in the case of ammonia, plugging of downstream piping and equipment by the formation and build-up of stable ammonia salts. In addition, hydrocarbons can, under certain conditions, lead to significant soot formation in the reaction furnace, giving rise to a soot-contaminated sulphur product in the first sulphur condenser.

Fig. 6: **Gas temperature**



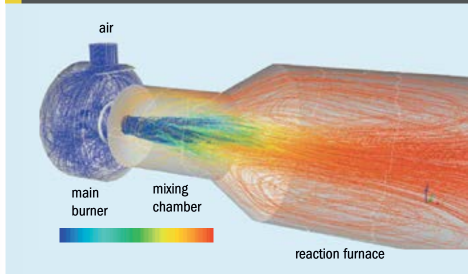
Source: Duiker

Fig. 7: **Oxygen depletion**



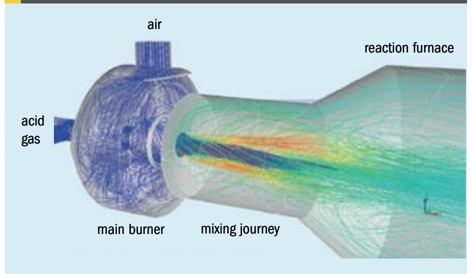
Source: Duiker

Fig. 8: **Reaction furnace sulphur formation**



Source: Duiker

Fig. 9: **Reaction furnace sulphur dioxide formation**



Source: Duiker

Theoretical destruction efficiency and kinetic limitations

Thermodynamic calculations clearly show that no significant amounts of ammonia or hydrocarbons exist in the RF effluent at chemical equilibrium, which means that any breakthrough of these compounds must be due to the effect of kinetic limitations in the reaction furnace. The destruction mechanisms are often considered to be based on the oxidation of these compounds directly by oxygen, but kinetic experiments performed by the Alberta Sulphur Research Ltd (ASRL) have shown that H_2S clearly outcompetes both hydrocarbons and ammonia for the limited available oxygen, which is indeed expected when comparing relevant combustion properties such as the flame speeds and auto-ignition temperatures of these different compounds[4].

Duiker's kinetic simulations based on detailed chemical reaction schemes (both in ideal plug-flow configuration as well as with full-scale CFD modelling of the burner/RF system) also show that oxygen reacts most rapidly and, therefore, predominantly with H_2S and sulphur species in the combustion zone of the reaction furnace and that only small amounts of hydrocarbons and NH_3 are converted by direct reaction with oxygen.

At the same time, Duiker's field observations confirm that, with high-intensity H_2S burners, and provided that minimum RF temperature and residence time requirements are met, very high destruction efficiencies are achieved in practically operating units, indicating that other chemical mechanisms must indeed play a role in the destruction of hydrocarbons and ammonia.

Hydrocarbon conversion under RF conditions

In Duiker's CFD models of the burner/RF systems, hydrocarbons do not react significantly with the free oxygen in the combustion zone of the reaction furnace. However, even in the absence of free oxygen, hydrocarbons can still react with sulphur species and water to form carbon disulphide (CS_2), carbon monoxide (CO), H_2S and H_2. For example, for methane (CH_4):

$$CH_4 + 2S_2 \rightarrow CS_2 + 2H_2S \quad (7)$$

$$CH_4 + H_2O \rightarrow CO + 3H_2 \quad (8)$$

where H_2S is subject to dissociation via reaction (5) and where CO interacts with H_2O in the reversible water-gas-shift reaction:

$$CO + H_2O = CO_2 + H_2 \quad (9)$$

to form H_2 and carbon dioxide (CO_2). In addition, hydrocarbons dissociate to form hydrogen and carbon (soot), which can be converted by oxygen-containing species such as H_2O and CO_2 or possibly react with sulphur species to form more CS_2.

Laboratory experiments by ASRL[5,9] confirm that, under RF conditions, both aliphatic and aromatic hydrocarbons lead to significant amounts of CS_2 and, at lower temperatures, also to soot formation and breakthrough of unconverted hydrocarbons. Aromatic hydrocarbons like benzene and toluene prove most difficult to convert at RF conditions due to their chemical stability, so that practical guidelines for dealing with aromatic hydrocarbons include a minimum RF temperature

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of 1,050-1,100°C and a residence times of at least 1.5 seconds[3,6].

Ammonia conversion in RF conditions

In Duiker's CFD-simulations of the burner/RF systems with detailed chemical-reaction modelling, it was also found that ammonia does not react significantly with free oxygen in the combustion zone of the reaction furnace (as a consequence of the rapid reaction of the oxygen with H_2S and sulphur species). ASRL[7,8] has also determined experimentally that ammonia dissociation to nitrogen (N_2) and hydrogen (H_2) is strongly inhibited by both H_2O and H_2S, so that this mechanism is also unlikely to contribute significantly to NH_3 destruction in the burner-RF system.

However, it is also found by ASRL[7,8] that NH_3 reacts readily with SO_2 even at relatively low RF temperatures according to the reaction:

$$NH_3 + ½SO_2 \rightarrow ½N_2 + ½H_2S + H_2O \quad (10)$$

where again H_2S is subject to dissociation via reaction (5) to produce both H_2 and sulphur and where H_2S can react with SO_2 to produce sulphur according to the Claus reaction (2). Together with the direct oxidation of H_2S by free oxygen in the combustion zone as given by reaction (1), the overall effect of reaction (10) in the reaction furnace is the indirect oxidation of ammonia by oxygen to nitrogen (N_2) and water (H_2O).

Duiker's kinetic calculations using detailed chemical reaction schemes indeed show a significant enhancing effect of SO_2, and to a lesser extent of CO_2, on ammonia conversion at RF conditions, although the level of conversion in these calculations is underestimated when considering the very high ammonia destruction levels that are observed in the field with the high-intensity H_2S burners. The proper destruction of NH_3 is generally considered to require reaction furnace temperatures of at least 1,250°C and a residence times of 1 second. Interestingly, Duiker's full-scale CFD simulations under these conditions tend to show higher levels ammonia destruction than its kinetic calculations based on ideal plug-flow configurations, pointing at the role of the flow and mixing patterns in the burner/RF system.

Effect of high-intensity mixing

As stated, sufficient temperature and residence time in the reaction furnace are essential requirements for proper impurity destruction, but significant breakthrough of hydrocarbons or ammonia can still occur if the mixing in the reaction furnace is inadequate.

Duiker's CFD simulations with reacting-flow modelling show how the chemical conversions can easily become mass-transfer limited, particularly in certain parts of the combustion zone and at the final sections of the reaction furnace. Indeed, when mixing is poor, raising RF temperatures or increasing residence times beyond minimum levels becomes less effective, and these actions are no substitute for intense, well-controlled mixing patterns in burner/RF systems.

In addition, Duiker's CFD models show how the intense mixing induced by the burner brings hydrocarbons and ammonia impurities in close contact with sulphur species and SO_2 already generated by the (partial) oxidation of H_2S. In fact, to accommodate the full oxidation of the hydrocarbons and ammonia impurities in the H_2S feed, more air or oxygen is normally introduced via the burner. Since this oxygen is found to react predominantly with H_2S rather than with the impurities themselves, even higher concentrations of SO_2 and sulphur species are created in the combustion zone when impurities are handled, and these compounds are then found to interact with the hydrocarbon and NH_3 impurities by intense mixing.

Such chemical interactions, facilitated by favourable and well-controlled flow patterns, could contribute significantly to the high levels of impurity destruction observed in the field with the high-intensity H_2S burners.

Sulphur by-products

Carbonyl sulphide (COS) and carbon disulphide (CS_2) are undesired sulphur by-products that, unless effectively converted in the first catalytic stage of the Claus process, reduce the sulphur recovery of the modified Claus process.

While COS formation in the reaction furnace is associated primarily with the reactions of H_2S and sulphur species with carbon oxides (CO_2 and CO), CS_2 is formed in the reaction furnace as a direct result of hydrocarbon destruction.

Again, thermodynamic calculations show that, at least for CS_2, a very low concentration exists in the RF effluent at chemical equilibrium, indicating that the conversion of this species is kinetically limited at RF conditions. Besides several other reactions involving various species, COS and CS_2 can be converted in the reaction furnace by hydrolysis reactions:

$$COS + H_2O = CO_2 + H_2S \quad (11)$$

$$CS_2 + 2H_2O \rightarrow CO_2 + 2H_2S \quad (12)$$

Laboratory experiments by ASRL also show significant conversion of CS_2 with SO_2 to form CO, COS, and sulphur, as well as other reactions paths involving hydrogen and CO_2.

Duiker's field data show that particularly the CS_2 concentration in the RF effluent can deviate significantly from the equilibrium state of reaction (12). In reaction furnaces handling hydrocarbons, CS_2 is nearly always found in the RF effluents even at high furnace temperatures, indicating that adequate mixing is important right up to the final sections of the reaction furnace to reduce mass-transfer limitations. As already stated, mass-transfer processes in the reaction furnace can easily become rate-limiting, so that enhanced CS_2 conversions are indeed expected when strong and efficient mixing patterns are created throughout the reaction furnace. Duiker's CFD simulations clearly reveal these mixing patterns as created by the high-intensity H_2S burner, and this may, in itself, explain the typically lower CS_2 concentrations found in the RF effluents. CS_2 conversion may also be facilitated by flow patterns that enhance the chemical interactions of CS_2 with species like SO_2 (as explained earlier), but this effect on CS_2 conversion in the reaction furnace is currently unclear.

Total cost of ownership

Driven by international regulators demanding the minimisation of sulphur emissions, installing and operating a sulphur recovery unit (SRU) is an unavoidable investment for many operating companies. Although the design, detailed engineering, installing and operating of these SRUs are considered a well-developed, mature industry, the investment evaluations are often still performed within a framework which is not designed for this purpose. Despite the fact that the SRU generates large amounts of energy and produces elemental sulphur which is a saleable product, at the bottom line, the SRU does not contribute to the margin but is a net cost centre. Thus, instead of performing a traditional evaluation designed for a profit centre, which is often focused on return on investment or a short depreciation period, the focus should lie with the total cost of ownership (TCO) of the unit.

Considering that most projects are broken down into distinct phases (e.g. front end engineering design (FEED), engineering and procurement (EP) and construction(C)) and that these phases are often executed by different parties, it should also be considered when and by whom this evaluation should be done. Although most operating companies internally evaluate the capital expense (capex) and operational expense (opex) related to FEED proposals, the EP(C) proposals often are evaluated based on only the capex or total installed cost (TIC).

Furthermore, as EP(C) contracts are often signed on a lump sum basis, generally in this stage of the project, no involved party engages in any further evaluation. Thus, for most SRU projects, only one evaluation takes place and this is at the front end of the project.

What is thus often underrepresented in this process are the non-direct, long term costs and benefits associated with the different equipment available to the operators. Summed up by George Orwell in: "All animals are equal, but some animals are more equal than others."; an approved vendor list provides only a rudimentary safeguard against poor performing or untested vendors but no basis for an evaluation between their offerings. Considering an elevator, an escalator and stairs, it is evident that although they all perform the same core function, the costs associated with them are not.

For operating companies it is thus in their own best interest to weigh options and proposals internally and by stakeholders whom are familiar with the scope. For an SRU, in addition to the capex and opex evaluation based on figures presented by outside sources, this evaluation can include for instance: labour cost due to maintenance and repair, catalyst lifetime differentials, required shutdown schedule, consumables consumption, etc. Considering these additional parameters it is clear that some SRUs are definitely more equal than others.

High-intensity burners

As discussed earlier, high-intensity burners are differentiated from non high-intensity burners not simply by the fact that they perform the same function quicker, better or more efficiently, they perform the function in a completely different manner. The resulting benefits: higher sulphur production in the reaction furnace, better destruction of impurities and lower CS_2 concentrations in the reaction furnace effluent, are well established through anecdotal evidence. So although the technical benefits of installing a high intensity burner in the main reaction furnace of an SRU are generally accepted and acknowledged, how this translates to the bottom line is much less clear.

Considering the function and the expected service life of an SRU, it becomes evident that one factor governs any type of TCO analysis performed; reliability. Unscheduled downtime will govern any TCO analysis performed due to loss of production and repair costs involved. Consider the repair of a tube breach in a waste heat boiler. Even in small facilities this activity can take a week simply due to the fact that a controlled cool down is required before the repair can take place. After performing the repair the reaction furnace needs to be slowly heated up to prevent refractory damage.

From a financial perspective, reliability for any process critical part of the SRU is thus so crucial that from a TCO perspective it makes no sense even evaluating an alternative to the most reliable equipment available.

For the TCO evaluation of high-intensity burners as well as the sake of model simplicity it is possible to look at two distinct effects which are directly related to the mentioned technical benefits: catalyst selection and the scheduled turn around period.

Although not all catalyst bed degradation can be ascribed to poor combustion, RF performance determines the composition of the process gas stream and the quantity of impurities that the catalyst beds are exposed to.

It is clear however that the complete destruction of aromatics and limiting the CS_2 exposure of the catalyst beds leads to different selection criteria for the type of catalyst to be utilised. The effect on the TCO is very significant as the prevention of having to resort to using high grade catalysts has a recurring effect with every catalyst change.

Furthermore, it has been found that a cleaner process gas extends the effective catalyst life. This effect is also recurring since often a larger turnaround is scheduled around the replacement of the catalyst.

This extension is not only beneficial through reducing the expense on catalyst material, the extended cycle also reduces the maintenance expense.

Taking these different effects into account, it makes sense to evaluate investment decisions not only from a FEED evaluation perspective, but from a detailed engineering perspective as well.

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Fig. 10: **Typical Siirtec Nigi acid gas burner assembly**

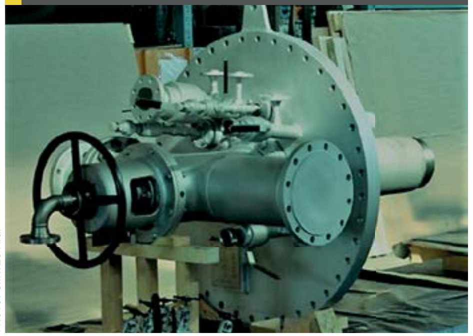
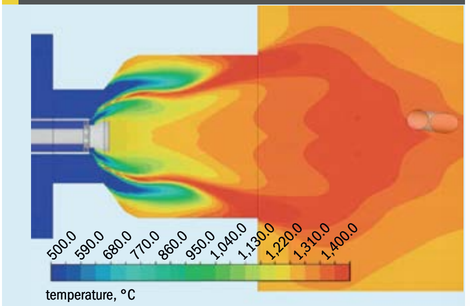


PHOTO: SIIRTEC NIGI

Fig. 11: **Temperature profile of new Siirtec Nigi burner**



Source: Siirtec Nigi

Revamping the SRU thermal section

Over the last ten years Siirtec Nigi has been requested by many refineries and gas processors to study the revamp of existing Claus plants to treat new gas compositions and to meet new capacity requirements, while minimising the investment costs and reducing as practically as possible the shutdown period for the site activities.

To meet these demands Siirtec Nigi has developed a new, high performance thermal section (burner + furnace), which can be considered for the revamp of existing Claus plants to boost the overall sulphur recovery efficiency[10].

It is well known that the capacity of an existing Claus plant can be increased by adding oxygen to the combustion process. The level of air enrichment is in the range 30-40 vol-% oxygen when refinery acid gas is treated. Higher oxygen enrichment, up to 100% pure oxygen is applied to SRUs with dilute acid gas feed streams.such as those typically found in natural gas production fields.

Siirtec Nigi has many years of experience in the design, fabrication and supply of acid gas burners for SRUs, especially for operation with oxygen enriched air. Burners have been supplied and installed to over 120 Claus plants worldwide (Fig. 10).

In the past decade Siirtec Nigi has invested particular effort to the improvement of its own acid gas burners and reaction furnace designs, they are treated as a single coupled system that must be properly handled and designed.

In addition to being an SRU licensor, EPC contractor and supplier of critical items of SRU equipment, Siirtec Nigi also acts as an integrator in the early stages of projects, using its extensive experience and knowhow to understand and interconnect all critical aspects of these systems to deliver successful outcomes.

Improved acid gas burner design

Some of the key challenges for the improved acid gas burner design were:

- to design the burner for acid gas combustion at high temperature i.e. 1,550-1,600°C, avoiding damage to the burner lance caused by overheating; to achieve this, the burner should be designed to maximise the cooling effect of the acid gas and air streams and to expose the burner tip to combustion products at temperatures lower than the expected adiabatic temperature.
- to obtain a short flame length with no refractory impingement, maximising the reaction furnace volume available for the post flame reactions; the flame front should also be sufficiently wide so that no channelling of combustion products takes place in the reaction furnace.
- to avoid vibrations and noise, as typically noted in the operation of some high intensity burners, to assure smooth burner and plant operation
- to design the burner for low pressure drop on both the acid gas side and the combustion air side; this requirement is very important in case of Claus plant revamps, since the existing air compressors should be retained to minimise investment cost.

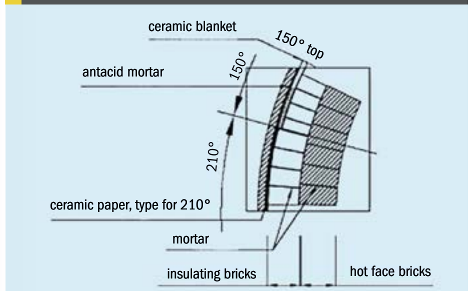
Siirtec Nigi have successfully implemented all of the above requirements in the design of its latest acid gas burners. The new burner design benefits from sub stoichiometric combustion of the acid gas. Because of the relatively low air/acid gas volumetric ratio, the high velocity wide-angle injection of acid gas into the air promotes a swirling motion of the reactants achieving good mixing and a good temperature profile. This is particularly important for oxygen enriched air operation.

Key features of the improved burner design include:

- The combustion air box has been redesigned internally to assure uniform distribution of the air stream all around the acid gas lance; pressure drop on air side has been kept at 250-300 mm w.c. as typical of the traditional Siirtec Nigi burner and as result no increase of the noise level has been noted over the typical 75-80 dBA range.
- The acid gas lance has been provided with a proprietary tip design which promotes the swirling motion of combustion products; this performance has been confirmed by numerous CFD analyses performed on the coupled burner-furnace system. The CFD analysis is performed using a suitable kinetic model representing the typical reactants pool present in the thermal stage of a Claus unit and is supported by the back-up of a consistent and updated plant data collection and by collaboration with respectable universities.
- The flame core temperature has been found to be systematically higher than the adiabatic combustion temperature which is beneficial for the kinetics of contaminant destruction reactions.

SRU THERMAL SECTION

Fig. 12: **Optimised design of reaction furnace**



Source: Siirtec Nigi

Fig. 13: **Pre-formed bricks around manhole**

PHOTO: SIIRTEC NIGI

- The pressure drop on the acid gas side has been kept below 400 mm w.c., which is beneficial for the total pressure drop of the SRU, as advised for plant revamps.

Fig. 11 shows a CFD temperature profile of the new Siirtec Nigi burner. Acid gas burners of this design have been supplied and tested since 2010. References include SRUs operated with combustion air only e.g. for Viscolube plant, Italy, (2010), CPLC refinery, India (2012), Afipski refinery, Russia (2015) and Pavlodar refinery, Kazakhstan (2016), and SRUs designed for oxygen-enriched air operation at Iplom refinery, Italy (2010) and Sines refinery, Portugal (2010).

The burner performance has been satisfactory for both high temperature combustion and for destruction of contaminants present in acid gas streams. The good results and feedback from clients has been instrumental in the continuing improvement and optimisation of Siirtec Nigi burners. Recently new burners have been supplied to CPCL refinery, India 2017 and Taranto ENI refinery, Italy (2018). In ENI refinery the new burners are specifically designed for oxygen enriched air to increase the SRU capacity by 35%.

Improved reaction furnace design

Siirtec Nigi has also devoted much effort in recent years to improve the reliability of the reaction furnace, with particular focus on the hydraulics and refractory stability. Both aspects are important for high temperatures of oxygen enriched air combustion and for big furnaces with large diameters.

The oxygen-enriched reaction furnaces supplied by Siirtec Nigi for the Shah Gas Project are among the largest in the world (up to approx. 6 m in diameter). Special attention was required to evaluate the thermal stresses across the junction where the thermal furnace connects to the downstream waste heat boiler, to evaluate furnace cooling for conditions deviating from normal operation, as well as to address design challenges related to the correct calculation and installation of the refractory linings.

The improvements to the hydraulics and refractory of the reaction furnace design are summarised below:

- The hydraulic performance of the reaction furnace has been optimised by installation of high efficiency burners able to generate a relatively short flame with a large volume and distribute the combustion product gases across the whole section of the furnace, thereby avoiding channelling of hot gases and maximising the residence time
- The refractory lining of reaction furnace has been improved by applying the following design criteria:
  - hot face refractory layer has been assembled with properly tapered high alumina bricks to reduce the risk of sagging;
  - a radial expansion joint filled by ceramic blanket has been provided at the top of the furnace to accommodate the differential thermal expansion between the refractory and the furnace casing, thus avoiding plastic deformation of the bricks at high temperature (Fig. 12);
  - pre-fired blocks are installed around the openings such as manholes, nozzles etc. to improve the stability of the hot face refractory layer in those areas (Fig. 13).

Siirtec Nigi has implemented medium-to-high oxygen enrichment levels in several refineries, including: API Falconara Refinery, Porto Marghera Refinery and Taranto Refinery in Italy and Barrancabermeja Refinery in Colombia. For these references, due to the maximum temperature limits of the high alumina refractory, oxygen cannot simply be added to the acid gas burner, highly specialised staged oxygen burning is required.

An uncommon but key benefit of Siirtec Nigi reaction furnaces is the flexibilty to design them with oxygen enrichment capability already built-in should the client decide to implement it at a later date. This design was provided for Taranto Refinery, Italy (2007), Sannazzaro Refinery, Italy (2007) and Sines refinery, Portugal (2010); oxygen enriched capability was included in the design from the beginning allowing these units to be operated at increased capacities by basically switching to a new oxygen enrichment acid gas burner, without having to re-consider all the critical integration aspects that this switching operation would normally require, and significantly reducing down-time.

Reaction furnace internals to boost performance

The burner plays the most important role in the achievement of proper combustion in the SRU reaction furnace but the temperature in the combustion zone/front end of the furnace can be further enhanced by the preheating of the process gases and the combustion air, the co-firing of fuel gas, and the redirection of some of the acid gas flow towards the back of the reaction furnace (RF) to achieve a more stoichiometric combustion ratio.

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Fig. 14: **Failure of conventional cylindrical and matrix box checker walls**

PHOTOS: BLASCH

Fig. 15: **Blasch VectorWall**

PHOTOS: BLASCH

In terms of turbulence and mixing, even the best burners can't maintain complete mixing across the entire length of the reaction furnace and internal structures such as checker walls or choke rings are often deployed to promote mixing and provide other benefits[11].

Checker wall systems

The conventional roles of a checker wall in the reaction furnace are to help increase front zone temperatures, protect the tube sheet from radiant heat and improve mixing to some degree.

Conventional checker walls in SRUs either have a cylindrical shape to help resist high stress due to the geometry, or a matrix box shaped brick system jointed with mortar that can often fail due to thermal shock cycling, mortar failure and vibration. In addition to that, running the unit above its design capacity causes damage to the conventional checker wall as it cannot sustain high vibration at over-design flow rates. Fig. 14 shows damage caused to both checker wall designs. The high failure rate of checker walls leads to high repair costs from frequent and prolonged shutdowns and this cost exponentially increases if it leads to having to cut upstream production.

Damage to conventional checker walls due to loss of structural integrity can also lead to not being able to achieve the high temperatures in the front zone that are necessary for ammonia destruction, causing deposits of ammonium bisulphate/sulphate in the downstream equipment. This is another factor requiring shutdown of the SRU at significant economic cost.

Choke rings

A choke ring is used to reflect back some of the flow and create a degree of back mixing in the front zone of the furnace. However, a large portion of the flow jets through the center of the ring and jeopardises the achievement of the minimum residence time requirements in the furnace. Many plants also use a traditional checker wall in front of the tube sheet to protect it from impingement by this strong jet.

Blasch HexWall and VectorWall

Blasch HexWalls and VectorWalls have been successfully deployed in both refinery and gas plant SRUs ranging in size from under 100 t/d to over 2,000 t/d. Working jointly with process licensors, refractory suppliers and operating companies and with the help of sophisticated CFD analysis, Blasch has continued to improve the design of these critical RF internals.

Blasch's original objectives for a checker wall were to provide a structure that was more mechanically stable based on several customer complaints that their existing structures failed frequently and often didn't survive an entire campaign intact. The result was the development of the Blasch HexWall checker wall. The HexWall blocks which range in depth from 9 to 18 inches (23 to 46 cm) are designed to be stacked dry and are mechanically engaged through a series of tabs and slots, so the wall is quite stable, even when several metres in diameter. No mortar is used between the blocks, allowing the interlocking assembly to accommodate the thermally driven expansion and contraction that comes with RF operation. The walls may either be erected into a slot in the existing lining, or installed against the hot face brick with a course of brick on either side to lock it in.

Over the next several years, as the stability and durability of the HexWalls was proven, attention turned towards additional benefits that could be provided by refinement of the structure. In the context of the "3 Ts" of combustion (time, temperature and turbulence), the benefits of higher front zone temperatures had already been demonstrated, thus facilitating the important destruction of hydrocarbons, ammonia and BTX. The focus thus became on how to improve mixing in the reaction furnace (turbulence) and thereby also minimise any channelling /stratification of the gases and thus ensure sufficient residence time in the furnace.

A vectoring hood was developed that would fit into the outlet ends of the existing blocks in the HexWall design, and could be oriented in such a way as to redirect, or 'vector', the down-stream flow allowing the assembly to contribute to the creation of the overall desired flow. The vortex was initially selected because it was felt that this configuration made the best use of the furnace volume and created a flow pattern that yielded a long path length with a very tight residence time distribution. The configuration was designed to provide the flow pattern of a plug flow reactor and make the most effective use of the existing furnace volume. This variation of the HexWall checker wall was christened the VectorWall (Fig. 15).

It had been observed at VectorWall retrofits that the choke ring configuration seemed to allow a portion of the process flow out of the furnace well before any published minimum residence time numbers are met. It was believed that the dramatic improvements seen in the field with the VectorWall were due to the tighter residence time distribution and the tendency of the wall to keep the amount of

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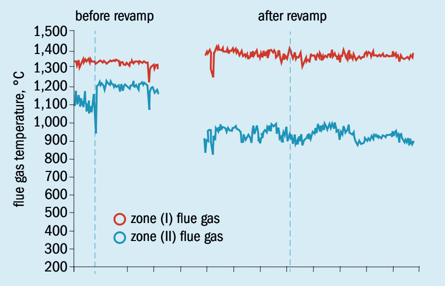
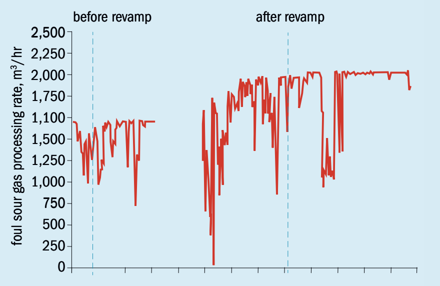
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33

Fig. 16: **Reaction furnace temperature before and after VectorWall revamp**



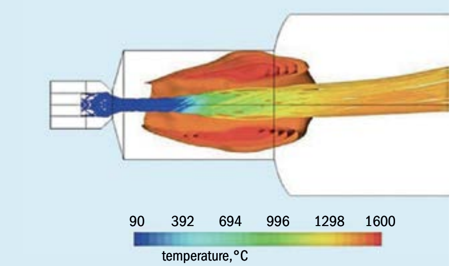
Source: Blasch

Fig. 17: **Gas processing rate before and after VectorWall revamp**



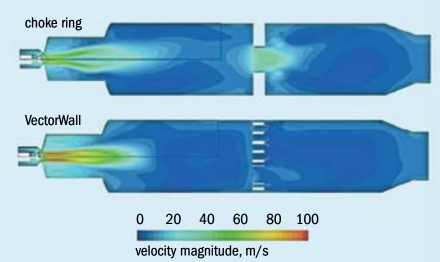
Source: Blasch

Fig. 18: **Mean flame shape with choke ring configuration**



Source: Blasch

Fig. 19: **Velocity magnitude comparison**



Source: Blasch

unreacted material from getting out of the furnace to a minimum. Subsequent CFD modelling confirmed this hypothesis.

Another advantage of the VectorWall, which is under constant refinement based on customer feedback, is that the size and angle of the vector hoods can be customised to provide the degree of mixing, shielding of the tube sheet, and to limit the heat loss from the front zone of the reaction furnace. There are now well over a hundred HexWalls and VectorWalls installed worldwide.

Based on a deepened understanding of the various benefits of VectorWalls and client feedback, it is felt that gas plant SRUs, which are often very large with the attendant concerns of stability of conventional checker walls and which also face the challenge of achieving adequate temperatures for BTX destruction, can stand to benefit the most from this advancement in sulphur recovery unit reaction furnace internals.

Fig. 16 compares the furnace temperatures before and after a revamp at a refinery that was experiencing serious problems with their checker wall and with ammonia destruction and decided to install a Blasch VectorWall. It can be seen that after the revamp, the Zone I temperature increased by about 100°C, thus solving the problem with ammonia destruction. The presence of the Vector hoods in the blocks also helped with reflecting more radiant heat back into zone 1. The refinery was also able to increase the sour water stripper gas (SWSG) by about 30% as seen in Fig. 17 and in addition no more furnace vibrations were observed as was the case prior to the VectorWall revamp.

The VectorWall has also been deployed in sulphuric acid plants to effect a more efficient and compact furnace design and also address issues relative to NOx which is always of concern in sulphuric acid regeneration (SAR) plants.

CFD modelling of choke ring and vector wall configurations

Detailed computational fluid dynamics (CFD) analyses were performed with Porter McGuffie, Inc. recently to characterise and compare the performance of a SRU reaction furnace at a refinery in Asia where the choke ring in the furnace had been replaced with a VectorWall. Prior to the revamp, when the reactor was equipped with a choke ring, the SRU was limited in capacity by vibrations and insufficient ammonia (NH_3) destruction. The latter, despite the acid gas being split between the front zone and the zone behind the choke ring to achieve more stoichiometric combustion and higher temperatures for better ammonia destruction.

After replacing the choke ring with a VectorWall, the SRU could process acid gas at higher capacity, achieved much better NH_3 destruction and vibrations were eliminated. The CFD analysis helped provide a theoretical understanding of this and other observations from the field by modelling the performance of the two reactor configurations with respect to velocity distribution, flame shapes, residence times (especially related to ammonia destruction requirements) and other parameters of interest.

Several key insights were gained from the CFD analysis:

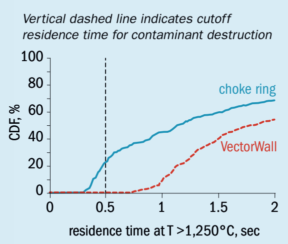
Improved flame characteristics and reduced vibrations

With the choke ring, pressure waves reflecting off the choke ring result in a flame shape within the burner can that likely caused the unstable vibrations during operation. As can be seen in Fig. 18, the flame spreads to the ID of the burner can's refractory and is not closed. Instead it is open, as shown by the centrally located streamlines released from the acid gas inlet passing relatively undisturbed through the core of the flame. This is unusual and indicative of poor combustion quality, possible refractory damage, and high pressure variations – likely manifesting as high in-service noise/vibrations. One of the important findings from the analysis was that the VectorWall caused a significant reduction in the interactions between the flow local to the burner and the separator.

Improved ammonia destruction

With the choke ring, a significant centreline jet formed through the separator as shown by the "bullet" shaped protrusion in the choke ring configuration versus the VectorWall configuration (Fig. 19), resulting in a spread in the residence time distribution and some of the flow passing through the reaction furnace without adequate residence times for completion of the desired reactions. One of the strongest manifestations of this is that 22.5% of the flow did not meet NH_3 destruction residence time requirements with the choke ring configuration per the CFD analysis. (Fig. 20). With the VectorWall, all of the Zone 1 gas flow meets retention time requirements for NH_3 destruction.

Fig. 20: **Cumulative distribution functions of residence time at T >1,250°C**



Source: Blasch

The low residence times in the choke ring configuration are consistent with field performance, as the choke ring configuration was found to have ammonium bisulphate/sulphate in downstream equipment, providing evidence of insufficient ammonia destruction.

Improved overall mixing and furnace operation

With the VectorWall, backpressure was reduced and a proper flame jet was formed from the burner throat with the flame extending out of the burner can (Fig. 19), resulting in a higher intensity flame and better mixing.

The absence of a centreline jet downstream of the separator in Zone 2 results in a very tight residence time distribution. The low temperature region resulting from the Zone 2 acid gas inlet just downstream of the VectorWall is smaller than that in the choke ring configuration due to improved mixing in Zone 2 with the VectorWall configuration.

Reduced pressure drop

Pressure drop through the VectorWall configuration is ~900 Pa lower than the choke ring configuration. The significant difference in pressure drop is likely caused by the spread of the flame in the burner can, which must then be turned back to pass through the choke ring.

Further potential improvements

Flow tracing methods indicate that blocking the manway of the VectorWall should further improve mixing and increase residence time beyond what has already been observed.

Temperature monitoring in the reaction furnace

One of the challenges in the reaction furnace of a sulphur recovery unit is to measure the correct temperature of the process gas[12]. In the past, thermocouples were prone to corrosion and/or measured the refractory temperature if not properly positioned. Pyrometers show sensitivity to fouling and drift over time and can also indicate the refractory temperature in case of misalignment. The performance of these instruments has improved over time via the introduction of purged ceramic sleeves protecting the thermocouple and better purge designs to maintain clear visibility through the pyrometer lens. But what should plant operators do when multiple instruments have been installed which are indicating different temperature readings? A high temperature indication could be construed that the temperature is approaching refractory limitations, which could lead to failure of the thermal reaction furnace and/or waste heat boiler protection system. A low temperature indication could be construed to be incomplete conversion of contaminants such as heavy hydrocarbons, BTEX or ammonia which may cause plugging and fouling in downstream reactors and condensers. Both underestimation and overestimation of the temperature indication can pose particular dangers and plant operators will respond in contradiction to the need of the actual situation in the furnace. In addition, start-up and drying-out operations pose other challenges as these operating conditions can lie outside the measurement range of the temperature instruments. Typically, dedicated start-up thermocouples or other means of temperature measurement may have to be used.

The question of which temperature measurement can be trusted is often posed to the licensors/engineering firms who can calculate an expected reaction furnace temperature using simulation software with validated calculation methods. These methods will include parameters such as composition of the gases entering the reactor and heat losses. Plant operators most often do not have the benefit of such simulation tools or heat models.

The Temp-Protect tool is a Jacobs development that calculates the temperature of the reaction furnace based on a heat balance correlation. The inputs for this calculation are measured signals which are already available in the DCS and analysis of the acid gas composition is not required. The benefit of this tool is a continuous calculation and prediction of the expected gas temperature. The main characteristics of this tool are:

- independent means of temperature indication of the reaction furnace;
- fast and precise reference point for the temperature readings of the reaction furnace;
- the tool can be used for all operating conditions: start-up, fuel gas firing, oxygen enrichment etc.;
- additional check on flow instruments of acid gas and fuel gas;
- tailored to each individual plant: geometry and design of the reaction furnace is included in the calculation as each design and installation has its own heat loss;

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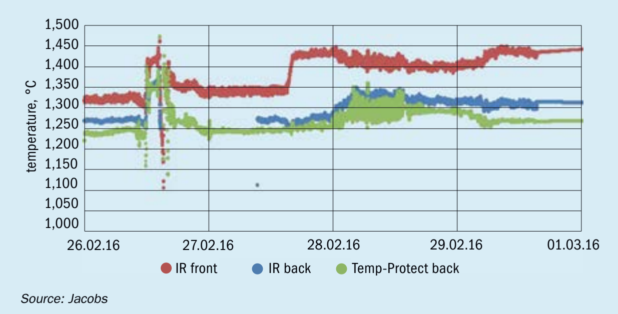
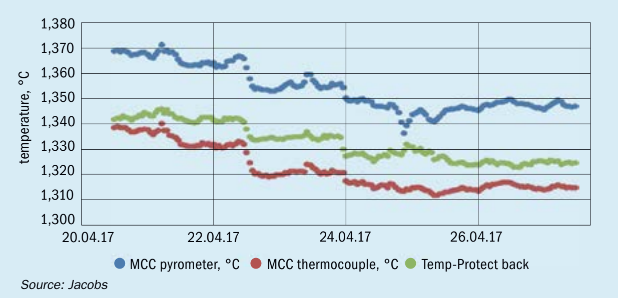
Fig. 21: **Case 1: reaction furnace temperature measurements**



Source: Jacobs

Fig. 22: **Case2: reaction furnace temperature measurements**



Source: Jacobs

- changing process conditions included: effect of composition, flow, preheat, etc.

The Temp-Protect output in DCS allows operators to check the validity of their reaction furnace temperature instruments via an independent value. Two case studies are presented to illustrate the functionality of the Temp-Protect tool.

Case 1

Temp-Protect was installed in a refinery SRU with two pyrometers (Fig. 21). A 100°C difference was measured between the two pyrometers which could not be explained by location only or a difference in heat loss alone. Recalibration of the front pyrometer was advised in this instance. Of particular interest in this scenario was to know whether the temperature was high enough for complete ammonia destruction. The green line represents the calculated values of the Temp-Protect tool which are in line with the back-end pyrometer. The total heat loss was taken into account which corresponds to the temperature reading at the back-end of the reaction furnace. Changes in flow and composition are captured by this tool as illustrated by the rapid response. Overall the Temp-Protect tool correlates well with the expected temperature of the reaction furnace.

Case 2

In this refinery SRU thermal reaction furnace, both a thermocouple and pyrometer were installed (Fig. 22). The difference in readings between the two instruments was only 40°C which shows proper calibration of both instruments. The Temp-Protect estimation of the temperature corresponds well with either one of the temperature instruments. Although in this scenario there was no need for verification of either instrument as both were properly functioning, this example does illustrate the potential of this tool. Whenever these readings are prone to diverge, the Temp-Protect reading can be used as an additional check-point to quickly assess which instrument shows a deviating value.

This check provides the operators with more security and reduces time spent on maintenance by having to check and recalibrate both instruments.

These cases illustrate the benefit of having additional temperature monitoring tools in place. There have been numerous incidents in the industry where overheating of refractory with subsequent failure of the furnace shell took place as plant operators relied on the temperature instruments which indicated temperatures that were too low. Addition of more fuel gas can result in temperatures well over 1,500°C. These incidents could potentially have been avoided if operators were warned via an independent temperature indication which would have led to a check of the instruments. As the Temp-Protect tool uses the flow signals of the acid gas and fuel gas streams, it can also serve as a check for the flow instruments belonging to these streams. ■

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