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Number 360

September | October 2015

SULPHUR

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Sulphuric acid in Europe

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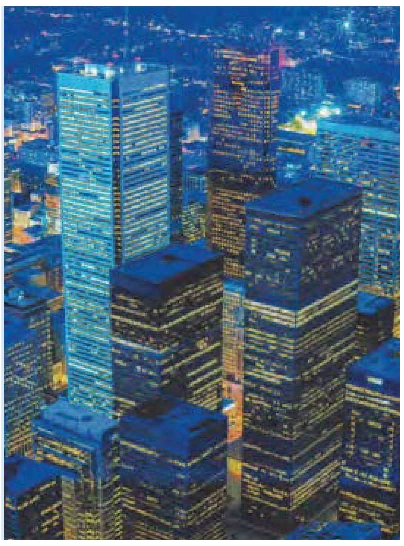

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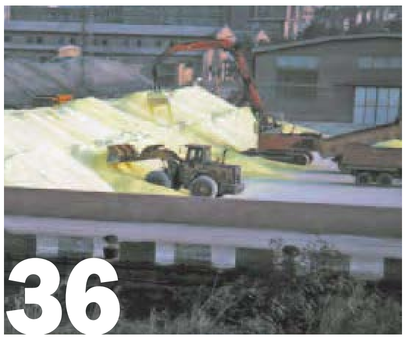
NUMBER 360 **SEPTEMBER | OCTOBER 2015**

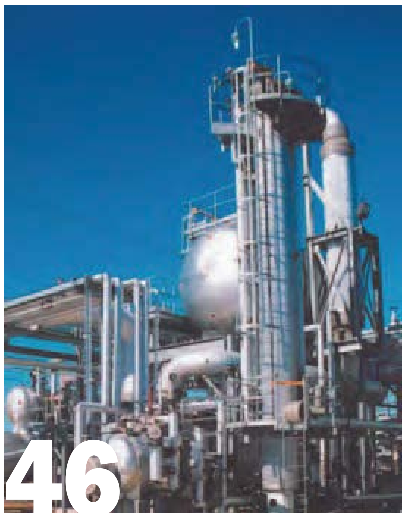
CONTENTS

REGULARS



Sulphur handling

Mitigation of airborne dust.



Sulphur recovery

Trends in sulphur recovery technology.

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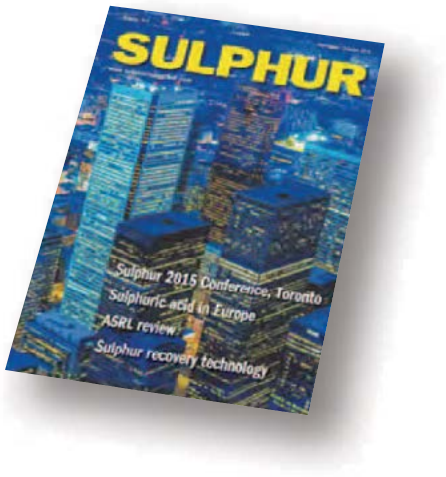
Published by: BCInsight

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46
47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84

China's slowdown casts a shadow over commodities



> **At the moment, the betting is still on a relatively soft landing**

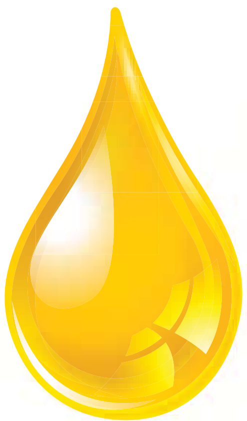
We have grown used, over the past few years, to the startling growth of China's economy – years of double digit growth which have taken it to become the second largest economy in the world after the US and, if you take the standard of purchasing power parity (PPP), may have already propelled it to the top spot. However, over the past couple of years the Chinese economy has been slowing and this year has seen fears over the Chinese economy spread into stock markets and especially the share price of commodity firms who have grown fat on supplying China's seemingly infinite appetite for raw materials of all descriptions.

Now China is facing a crunch on several fronts, with extremely high levels of domestic debt, a stock market crash that has wiped a third off domestic shares in the past couple of months, slowing GDP and industrial production numbers and, in the medium to longer term, a demographic shift as a result of the success of the country's 'one child' policy which is seeing far fewer young people entering the workforce at the same time as the country's elderly population is rapidly growing, leading to a shift towards priorities such as pensions and healthcare and rapidly rising wages even as the country tries to 're-balance' its economy from a primarily industrial and investment led developing economy to a consumption-led industrialised one. The upshot has been a steady and pronounced contraction in the key industrial demand items which have dominated global commodity markets in recent years – oil, steel, copper, coal, etc, coupled with overcapacity in domestic industries built to substitute for expensive foreign imports, such as phosphates, methanol and ammonia. Commodity markets across the board have been hit by China's slowdown, and the shares of companies like Glencore have slumped.

China is still posting GDP numbers in the 7% range, although there are concerns that this may mask even greater underlying weakness and/or that official statistics may be being 'massaged' to continue presenting a 'good news' message. Nevertheless, a glance at China's mid-ranked place in the GDP per capita stakes (around 80th, at $13,000, compared to developed world averages of $40-60,000) shows that it still has some way to go before it becomes a high income country, and hence its economy still has plenty of room for growth. So is this just a slowdown before a return to growth, albeit at lower rates than before, or is it as some insist the bursting of a bubble that could have catastrophic repercussions – the so-called 'soft' and 'hard' landing options? The opacity of China's markets and governance makes this hard to gauge, and as a result there are plenty of Cassandras who will tell you that the world is now facing a crisis even graver than 2008-9, as China's debt-fuelled boom leads to a crash on the scale of a Spain, or even a Greece, except larger. Others point to the more subtle danger of the 'middle income trap', whereby China becomes stuck like Brazil apparently is in a middle area where rising wages make manufacturing uncompetitive at the same time that low skills prevent penetration into service industry markets. At the moment, the betting is still on a relatively soft landing, and in the meantime growth in the US and Europe as low oil prices take the drag off economies there is helping to compensate for China's slump, but the future still looks very uncertain.

Sulphur and sulphuric acid markets have been fundamentally affected by China's breakneck growth. Chinese acid production has doubled over the past decade, and even though acid from smelting has increased by 250%, and China's imports of acid have gradually dwindled over that period, the increase in sulphur-burning capacity and stagnation of pyrites-based production means that in spite of sulphur production from sour gas the country has continued to suck in huge volumes of sulphur to feed its fertilizer and other industries, continuing to make it the world's largest buyer. A Chinese slowdown is unlikely to affect this too much immediately, but could affect the longer term potential for China to soak up the world's growing supply of sulphur.

Richard Hands, Editor



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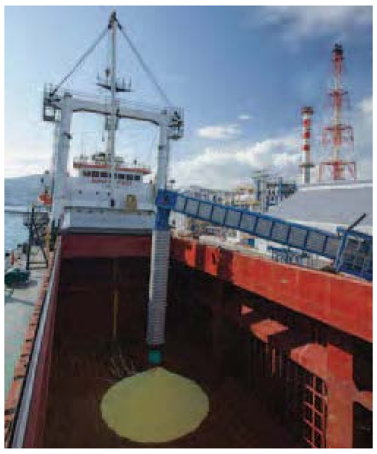
TO SEA.



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Price trends

MARKET INSIGHT

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

SULPHUR

Uncertain outlook

The economic uncertainty in China has led to an overwhelming impact on the global commodity market, and sulphur has not been immune to the effects. While Middle East producers increased sulphur prices in August for monthly contracts to $151-156/tonne f.o.b., market fundamentals have not supported the increases and a downward correction has since been seen. The downward price momentum has been driven by a combination of factors; China is at the forefront, with inventory stable around the 1 million tonne mark, a large portion of this believed to be in the hands of end users, rather than traders, further stalling market trading and activity. Demand in other markets such as India and Brazil has also been limited beyond regular contractual shipments. The bearish sentiment is expected to continue in the short term, with little support coming from macroeconomic conditions. Commodity pricing, including metals, have taken a hit, potentially impacting sulphur demand developments from leaching projects.

In China, prices have been dropping week by week, ranging $130-140/tonne c.fr in mid-September. The expectation is for further weakening, although industry sources anticipate the stand-off between sulphur producers and buyers will determine the next round of market pricing. Buyers are indicating lower price ideas and expectations, while producers are hoping a floor in pricing has already been reached. A key factor is that buyers appear to be relatively comfortable, with little pressure to enter the market for spot volumes. At the same time, excess liquidity in the market for producers and traders to places tonnage has not emerged, with most producers placing cargoes against regular contractual obligations. Exports out of the Black Sea have been under pressure, with a limit to additional spot volumes outside of contracts on offer. Low river levels have left barge loading capacity significantly reduced. At the same time, shipments to Tunisia from Russia have seen a recovery, following the stabilisation of processed phosphates production in the country.

The sentiment in India has also been muted, due to poor rainfall. Sulphur prices had crept up as high as $175/tonne c.fr, buoyed by the Middle East producer price increases. However, as with other import markets, prices have been steadily declining. At the start of September, prices dropped down to the $140s/tonne c.fr, as buyers remain comfortable with contract shipments in the near term. Reliance was also heard scrapping its regular online tender and rescheduling it due to a lack of demand.

New sulphur supply from the long awaited Shah gas project in the UAE is ramping up, with the project in commissioning and sulphur being exported via Ruwais. Production capacity has been estimated by industry sources at around 25-30% of capacity. It remains to be seen whether full capacity will be reached in 2015. Integer's view is that this will fall into 2016/2017. However, a significant portion of new production is pegged for shipment to Morocco, as OCP's expansion plans at Jorf Lasfar continue to progress.

In terms of pricing in the Middle East, Tasweeq dropped its September price by $18/tonne to $133/tonne f.o.b. Ras Laffan. For the month ahead, further prices drops are expected, particularly with the reluctance from China to accept current pricing. Tasweeq is also due to close a tender on 15 September, for October loading, which will be further test for market pricing and demand. Meanwhile, Adnoc set its September price at $135/tonne

Fig 1: **Chinese sulphur inventories**

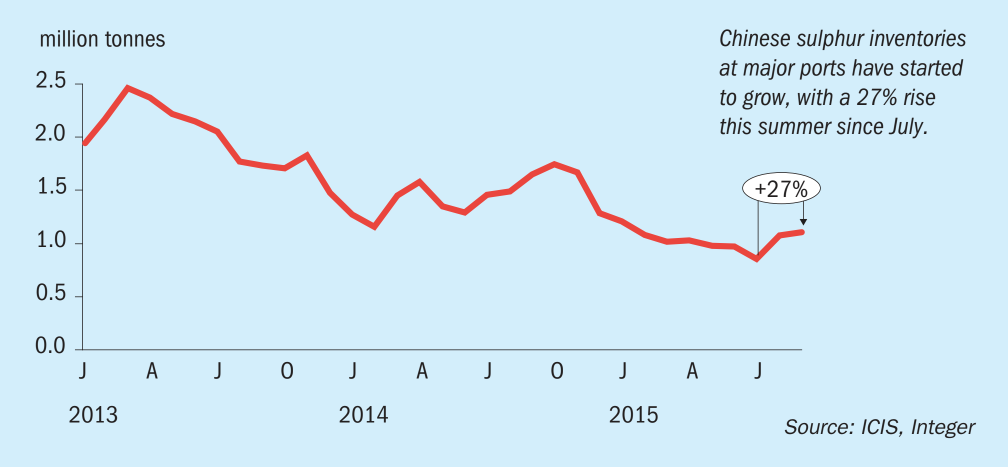
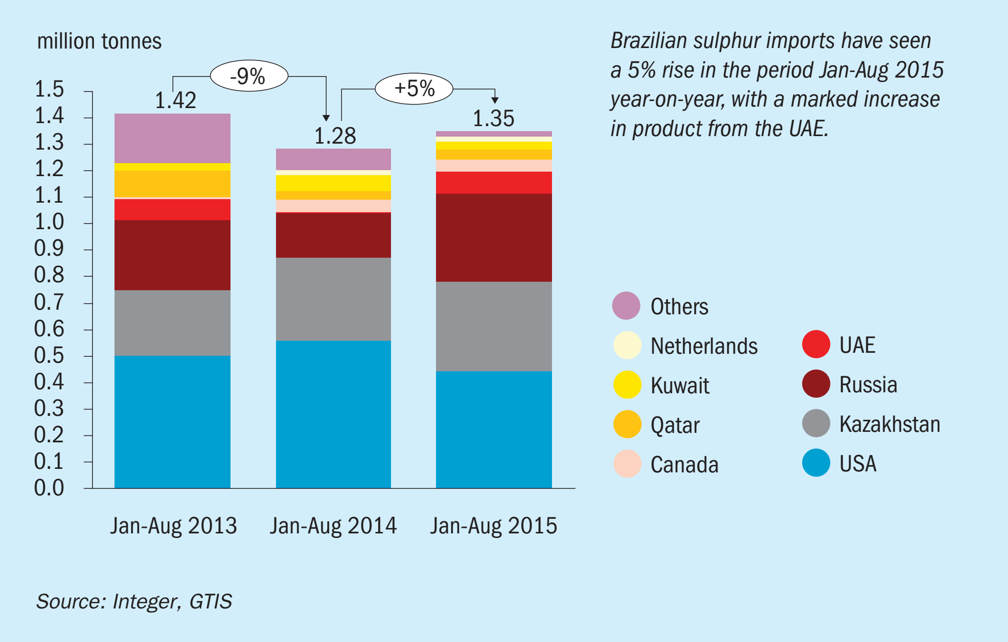


Fig 2: **Brazilian sulphur imports**



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f.o.b. Ruwais for cargoes to the Indian market. October pricing is likely to see further decreases, although a floor may be reached in the coming weeks, if buyers give in to the pressure. The outlook for the remainder of the year is relatively weak, but a more stable few months is expected once pricing finds a floor.

In Canada, oil sands production and energy companies have been under pressure, particularly in Alberta, with the oil price drop continuing to erode margins for many producers. Further compounding the situation, the rise in Alberta's corporation tax has taken its toll, with many companies announcing restructuring and job cuts in Calgary. However, despite this, sulphur production from oil sands continues to remain stable overall, with expectations of a slowdown in growth rates rather than any decline. Oil sands producers Syncrude and Nexen have both faced production disruption in September. Syncrude was hit by a fire at the end of August, impacting its upgrading facility. The timeline for the disruption remains unclear, with the extent of any impact on sulphur production yet to be quantified. Nexen was heard shutting down its Long Lake oil sands operations at the start of September following an order by the Alberta Energy Regulator (AER) over its pipelines. However, Nexen subsequently announced it would be able to maintain 75% production following an amendment order which lifted the suspension on a portion of the pipelines. Any slow down in sulphur availability from Canada in the outlook could contribute to supporting sulphur pricing. However, as the Mosaic remelter in Florida is on schedule to see commissioning in Q4 2015, Canadian exports to the US could see a decline, with a need to find an alternative market.

SULPHURIC ACID

Under pressure

Downward pressure has finally penetrated the global sulphuric acid market, following several months of stability. The export market out of Northwest Europe entered a seasonal lull through the summer months, due to the holiday season in the region. However, subdued buying interest from Brazil and the US Gulf, coupled with increased export availability within Latin America meeting some requirements, has taken its toll. Export prices dropped down by around $10/tonne to the low/mid-$20s/tonne f.o.b. NW Europe and spot deals are expected to remain under pressure in the short term. Smelter turnarounds at key producers Atlantic Copper and Boliden are unlikely to provide much relief to the market. Excess sulphuric acid supply at the port of Mejillones, Chile, led to exports to the US Gulf and Brazil, limiting demand from NW European smelters.

Acid prices in Chile dropped to $65-70/tonne c.fr in August, with healthy supply and limited demand supporting the reduction. Exports from Chile to other markets, highlighted the bearish sentiment. Prices are expected to remain under pressure for the remainder of the year, with negotiations for 2016 contracts to begin during Q4, this is expected to weigh on price ideas in the outlook. Freeport has decided to cut its production rate at its El Abra mine, may see acid demand drop down significantly.

Spot prices in Brazil have also softened, down to around $60-70/tonne c.fr into September. This is a significant drop on the prices up to around $90/tonne CFR in June, and reflects the additional acid availability in Latin America.

Asian markets have also been weaker through the start of September, with limited enquiries coming from key end user markets. A fire at Pan Pacific Copper's Tamano smelter occurred in September, with the smelter understood to have some technical issues. The various smelter turnarounds scheduled in the coming months is not expected to provide much relief to the market due to the lack of demand noted in import markets. Prices out of Japan and South Korea dropped to $10-15/tonne, under pressure from the overriding global trend.

In the US Gulf market, spot prices dropped to around the $60s/tonne CFR, with expectations this range would drop further for new business into the $50s/tonne CFR – although no new business was confirmed at this low level at the time of publication. Regional supply in the US was reported to be balanced overall, with domestic contract negotiations ongoing. The expectation is for slightly lower pricing, in line with the drop in sulphur prices.

Price indications

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

Cash equivalent	**March**	**April**	**May**	**June**	**July**
Sulphur, bulk ($/t)					
Vancouver f.o.b. spot	165-175	135-140	135	145-155	145-155
Adnoc monthly contract	140	140	150	150	155
China c.fr spot	150-160	130-160	155	150-168	150-168
Liquid sulphur ($/t)					
Tampa f.o.b. contract	145	132	132	137	137
NW Europe c.fr	170-200	170-200	185	170-200	170-200
Sulphuric acid ($/t)					
US Gulf spot	70-80	70-80	75	70-80	70-80

Source: CRU

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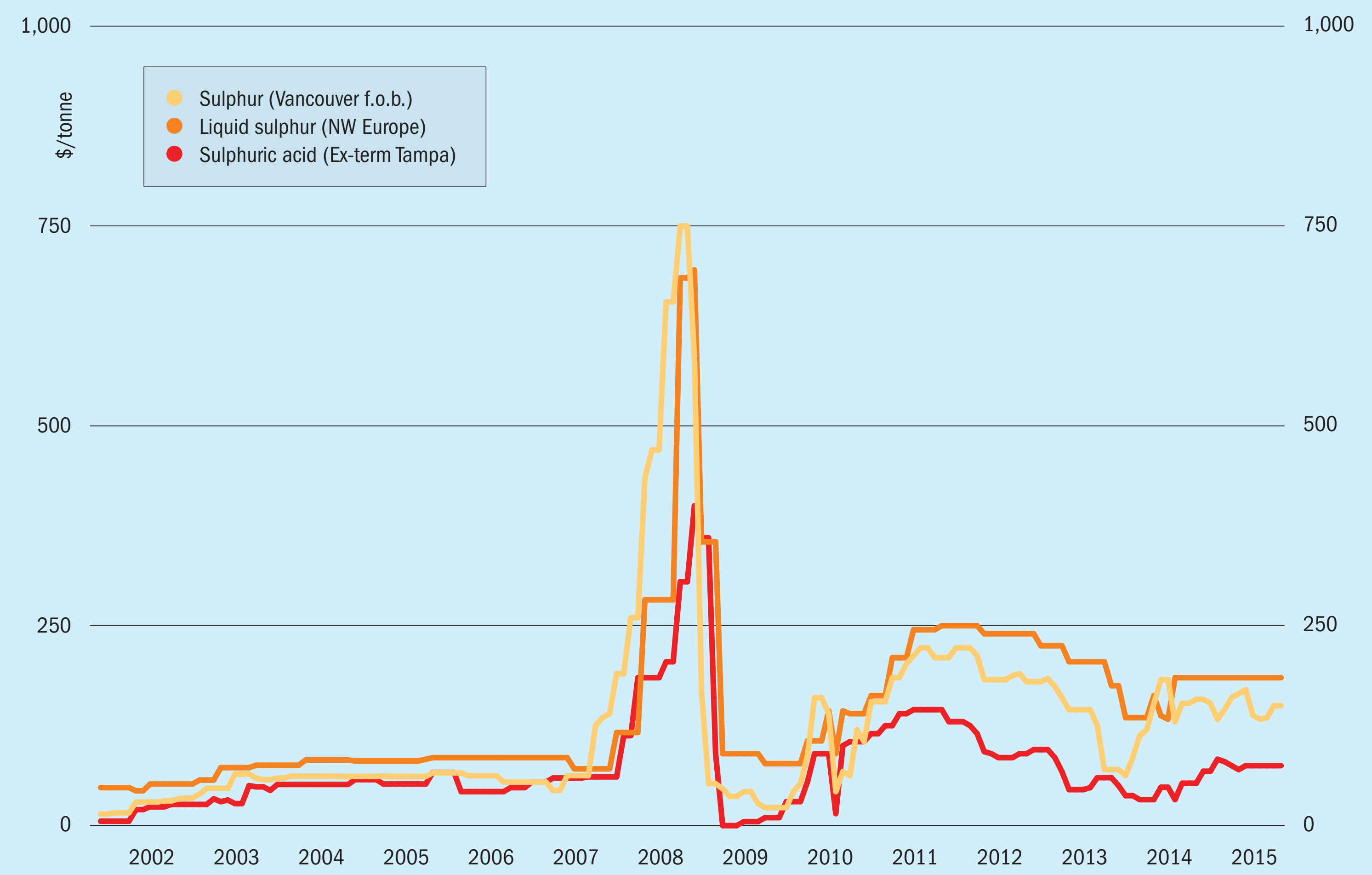
Market outlook

Historical price trends $/tonne



Source: BCInsight

SULPHUR

- Producers and buyers to remain in a stand-off in the short term – depending on end user requirements prices in the global market are likely to drop further, before seeing stability and any recovery.
- Chinese end users to continue to purchase sulphur on a hand-to-mouth basis through Q4 2015, with the new normal for inventory at ports to remain around the 1 million tonne market.
- Middle East producers likely to come under pressure in the coming months, due to the reluctance from buyers to accept prices, and an overall lack of interest for spot volumes from key markets such as India and China.
- As new production ramps up in the Middle East – this may further put pressure on the price outlook – although capacity at new projects is not expected to reach high levels until 2016. In the UAE, the continued commissioning of the Shah gas project is a key focus for the Middle East and will likely influence the market outlook over the next 12 months.
- Mosaic's sulphur remelter in Florida will be a key influence on North American trade. The project is expected to be commissioned on time and increased solid sulphur imports to the US are expected in the outlook.
- The economic situation in global markets, led by China, is expected to remain a bearish factor for sulphur and may put a ceiling on any potential recovery in pricing and demand
- **Outlook:** Prices will continue to soften through the start of Q4, but reach a floor as demand stabilises and end users look to replenish stocks ahead of the spring fertilizer season. While stability is anticipated, a major price recovery is not expected, unless the macro economic environment improves considerably.

SULPHURIC ACID

- Acid prices from NW Europe are expected to soften further and stabilise during Q4, owing to the limited number of turnarounds and ample supply seen in Latin America.
- Excess supply in Chile is expected to balance out in Q4, although negotiations for 2016 contracts are likely to be for price reductions due to the recent downturn in the market.
- Acid imports in China may soften, as we see sulphur prices falling, potentially motivating buyers to the sulphur market instead.
- The downturn in global commodity pricing is taking its toll on the acid market, expected to erode pricing and demand until stability is reached.
- Asian acid prices will likely follow the downward trend, despite the planned outages at smelters. Any reduction in Chinese imports will also lead to excess sulphuric acid in the market, at a time when there is limited spot demand.
- **Outlook:** A softer outlook for sulphuric acid prices is expected during Q4 2015, largely due to the downward pressure from sulphur, ample supply and the economic condition of the commodity market. A floor may be reached once any fresh demand for acid emerges in the spot market, but for the most part, contractual obligations will continue to form the majority of activity in the short term.

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Sulphur Industry News

SAUDI ARABIA

Bids in for Fadhili gas plant

Several engineering firms have submitted bids to build a gas plant at Fadhili in eastern Saudi Arabia for Saudi Aramco at an estimated cost of $5-6 billion. The project, which will process 2.5 bcf of sour gas per day, has escaped the rescheduling and shelving of several major projects that Aramco has been engaged in since the fall in oil prices has impacted upon state finances. Sour gas will be supplied from the onshore Khursaniyah and offshore Hasbah fields.

Bidders for the construction contract include South Korea's Daelim Industrial, Hyundai Engineering and Construction and Britain's Petrofac, as well as three consortia, comprosing respectively South Korea's GS Engineering and Construction with Spainís Tecnicas Reunidas, Italy's Saipem with Japan's JGC, and South Korea's Samsung Engineering together with Daewoo E&C. The project is split into three construction packages for the gas processing unit, utilities and offsite facilities such as nitrogen, steam, power and water systems, and sulphur recovery.

Aramco says that Fadhili is due onstream in 2019, by which time, together with Aramco's other gas projects in Wasit and Midyan, the company will have added more than 5 billion scf/d of non-associated gas processing capacity. Saudi Arabia is keen to boost gas use in the country in order to free up more oil for export.

KUWAIT

Refinery contracts awarded

The Kuwait National Petroleum Co (KNPC) has awarded $11.5 billion in contracts for the construction of the new al-Zour oil refinery, one of the largest in the region, with a projected capacity of 615,000 bbl/d. KNPC has awarded the main $4.25 billion refinery construction contract to a consortium including Spain's Tecnicas Reunidas, China's Sinopec and South Korea's Hanwha Engineering and Construction, while a consortium including Daewoo Engineering and Construction, Hyundai Heavy Industries and Fluor Corp of the United States will build support units and infrastructure services, valued at $5.74 billion. The $1.5 billion contact for the marine export terminal was won by Hyundai Engineering and Construction, SK Engineering and Construction and Italy's Saipem. KNPC has said that the final contract is expected to be awarded in the next few weeks, with sign-off on all of the contracts scheduled for October. Start-up is now due for late 2018 or early 2019. The project faced cancellation in 2008-9 as oil prices dropped, and in spite of re-approval in 2011-12, there have been further delays due to bureaucratic wrangling within Kuwait.

Amongst other product streams, the refinery will supply 225,000 bbl/d of low sulphur fuel oil (LSFO) to local power stations. Recovered sulphur from Al-Zour is expected to be 500,000 t/a at capacity.

CHINA

Chuandongebi start-up set for October

Chevron's delayed Chuandongbei sour gas project, which the company is developing in partnership with the China National Petroleum Corp. (CNPC), is now expected to start production by the end of October, according to Chevron. The $6.4 billion gas project, eight years in the making, has suffered several push-backs from its original 2010 start-up date, with disagreements between the project partners on the best way forward with the technically challenging project, in which Chevron is the operating company, and the holder of a 49% stake. The gas plant is designed to produce 258 million scf/d of sales gas in its first phase, rising to 558 million scf/d of gas in its second. Sulphur output will be 1.5 million t/a once the second phase is complete.

SOUTH KOREA

Contract awarded for residue upgrading expansion

Axens says that it has been awarded several contracts for the expansion of the existing residue conversion facilities at S-Oil's 580,000 bbl/d Onsan refinery in South Korea. The Residue Upgrading Complex Project (RUCP) is aimed at reducing fuel oil production while producing propylene through the conversion of atmospheric residue and will include the world's first commercial high severity FCC unit (HS-FCC™). The HS-FCC technology has been developed by an alliance between Saudi Aramco, JX Nippon Oil & Energy Corp. (JX), King Fahd University of Petroleum and Minerals (KFUPM), and is licensed by Axens and Technip Stone & Webster. The technology produces higher yields of propylene and other light valuable products than conventional fluidized catalytic cracking units.

Axens will supply the following technologies for the complex:

- an atmospheric residue desulphurisation unit (Hyvahl™) for the production of diesel and improvement of residue quality, including a permutable reactor system;
- a high severity FCC unit for conversion of the hydrotreated residue produced by the Hyvahl unit. The HS-FCC technology maximises propylene production using an innovative downflow reactor;
- an unsaturated liquefied petroleum gas (LPG) extractive sweetening unit (Sulfrex™) – for the treatment of the LPG cut originating from the HS-FCC unit upstream of polymer-grade propylene recovery process.
- a selective desulfuriphation unit (Prime-G+™) for the treatment of the HS-FCC gasoline;
- a C4-stream processing section including a C4 selective hydrogenation unit, MTBE unit, super-fractionator and a butane isomerisation unit. This section will produce MTBE and 1-butene which will be used as a co-monomer in polymerisation applications, as well as isobutane feed for an alkylation unit.

The company will provide technology licenses, basic engineering, catalysts, adsorbents and proprietary equipment.

POLAND

Tecnimont to upgrade Gdansk refinery

Maire Tecnimont SpA says that that its subsidiary KT-Kinetics Technology SpA has been awarded an EPC contract by Lotos Asfalt, a subsidiary of Grupa LOTOS SA, to upgrade a refinery unit in the Gdansk refinery, as part of LOTOS' EFRA (Effective Refining) Project. Grupa Lotos is one of the largest refining companies in Poland, engaged in the extraction and processing of crude oil, as well as in the wholesale and retail of refined petroleum products. The overall contract value is estimated to be €304 million and the project completion is expected in 2018. The contract includes the implementation of a delayed

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coking unit, a coker naphtha hydrotreating unit, a hydrogen production unit (licensed by KT) together with ancillary units in the premises of the Gdansk refinery.

Pierroberto Folgiero, Maire Tecnimont Chief Executive Officer, commented: "This award confirms our strong technological orientation in the hydrocarbons value chain, which enables our clients to improve efficiency as well as products quality and mitigate environmental impact. Our distinctive capabilities have once again led us to achieve this outstanding result and consolidate a 10-year relationship with such a prominent client."

IRAN

Talks on Oman pipeline resume

Iran has begun fresh talks with and Oman over the prospect of constructing a pipeline across the Gulf of Oman to transport sour gas South Pars to the Omani port of Sohar. The two countries signed an agreement in 2013 over the long-mooted project whereby Iran will supply Oman with 10 bcm per year of gas. The pipeline will link with Iran's existing network at Rudan, east of Bandar Abbas, and run 200km overland to the coast at Kuh Mobarak, before travelling 200km across the Gulf of Oman to Sohar. An Iranian consulting company has reportedly been selected to perform engineering studies on the construction of the pipeline, with the onshore and offshore phases being carried out simultaneously to speed up implementation.

Meanwhile the Pars Oil and Gas Company (POGC) has started underwater pipelaying operations for phases 20 and 21 of the massive South Pars gas field, carrying sour gas 105km from the production platforms to onshore processing facilities at Assaluyeh. So far 400m of the Phase 21 line has been laid, according to the company, with the platforms due to be in place by mid-September, once pipe laying is complete. Phases 20 and 21 of South Pars are slated to produce 50 million m^3/d of natural gas for domestic consumption, 1.0 million t/a of ethane for use by petrochemical plants, 1.05 million t/a of high-quality liquefied gas for exports and 75,000 bbl/d of condensate.

Iran looks to South Pars JVs

Iran intends to offer the South Pars oil layer and three gas fields for participation by foreign investors at an upcoming conference in London. The conference, planned for December, is aimed at attracting international investment into Iran's oil and gas sector, which could have up to $185 billion of projects up for grabs. The North Pars, Golshan and Ferdowsi gas fields are among nearly 50 projects which will be put up for investment under the new Iran Petroleum Contract (IPC) model, managing director of Pars Oil and Gas Company (POGC) Ali Akbar Sha'banpour is quoted as saying in Iranian state media.

The offshore North Pars field, shared with Qatar (as the South Field), is the world's largest, with estimates of 57.1 trillion cubic feet of sour (1% H_2S) gas. Golshan holds more than 50 trillion cubic feet of gas and is predicted to yield 2 billion cubic feet after development. Like Ferdowsi, Golshan is also offshore in the Arabian Gulf. The South Pars oil layer is estimated to hold 7 billion barrels of oil in reserves. Iranian Petroleum Ministry officials have said up to 35,000 bbl/d of oil are expected to be recovered from the layer in the first phase. Iran hopes to boost crude production to 5.7 million bbl/d.

MEXICO

New oil and gas bonanza in Mexico?

In a move that remains highly controversial within Mexico, the government is seeking to end state petroleum company Pemex's monopoly on oil and gas extraction with an ambitious programme of tenders over the next four years. Pemex has had sole control over Mexico's hydrocarbon resources since the end of the Mexican revolution in 1920, and in many quarters it is seen as a nationalist issue. However, falling oil and gas production and Pemex's losses, exacerbated by the fall in the global oil price which have led to the company's income falling by 50%, have persuaded the government that it is time to allow foreign investment into the country's oil and gas production. Consequently the Mexican Ministry of Energy has announced a plan to establish four rounds of tenders for exploration and extraction to take place between 2015 and 2019. The plan contemplates the auction of 244 oilfields for extraction, 379 areas of conventional hydrocarbon exploration, and 291 areas for the exploration of unconventional hydrocarbon resources. Amongst the reserves to be tendered are extra-heavy crude from the off the coasts of Tabasco and Campeche with an estimated volume of 16.7 billion barrels in depths from 20-400 m with high sulphur content.

Pemex itself meanwhile has looked to private equity funds to finance 15 offshore infrastructure projects and refinery upgrades worth $7 billion, as well as joint ventures for supplying rigs. However, the company is projected to run a deficit considerably higher than the $9.6 billion that the government has specified as a limit for 2015. In 2014, Pemex made $32 billion pre-tax profit, but duties and taxes turned that into an $18 billion loss. The company is asking for "flexibility" on its deficit, but the government is facing constraints elsewhere in state finances and is reluctant to do so.

From next year Pemex will face competition in domestic fuel sales, with full liberalisation set for 2018, the same year that new low sulphur fuel standards will become enforced, which are also placing pressure on Pemex as it tries to upgrade refineries.

UNITED STATES

Abrasion-resistant ceramics for oil sands operations

Blasch Precision Ceramics, Inc., has launched a new abrasion-resistant product line including ceramic lined elbows, pipe and spool linings specifically engineered for oil sands and fracking operations. The new CeraLine™ family of products exhibits exceptional wear and abrasion resistance which results in prolonged life. In the oil sands industry, much of the oil is extracted by mining, with hydro-transport (slurry) pipelines that carry the oil-laden bitumen from mine sites to refineries. They then return the waste sand and rock back to the mining sites to refill the pits. Ceramic provides a solution to the abrasive nature of the sand as well as a natural resistance to the high acidity of the tar-like bituminous oil sands.

New ceramic range.

"Our research staff continually strives to produce the best and most cutting edge materials and shapes in the industry," commented Dr. Keith DeCarlo, Blasch Precision Ceramics Research and Development Manager. "The wear and abrasion resistant properties of our CeraLine family of products make them perfect solutions for severe environments present in many processing industries worldwide."

INDIA

Bharat to double refinery capacity

State-owned Bharat Petroleum Corp Ltd (BPCL) says that it will invest $4 billion to double capacity at its 6 million t/a Bina oil refinery in Madhya Pradesh. BPCL, India's second-biggest state refiner after the Indian Oil Company (IOC), will initially invest $550 million in raising capacity of the Bina refinery to 7.8 million t/a by 2018, with a second investment phase of $2.8 – 3.1 billion over a five year period to raise output to 15 million t/a at the site. The Oman Oil Company (OOC), which has a 26% stake in Bharat Oman Refineries Ltd, will not be involved in the new investment, according to BPCL, which owns 49% of the refinery. The remaining 25% is held by various financial institutions.

BPCL also operates a 12 million t/a refinery at Mumbai and 9.5 million t/a unit at Kochi. It also has majority stakes in the 3 million t/a Numaligarh refinery in Assam. BPCL is also expanding and upgrading its Kochi refinery in Kerala to process high sulphur crudes by 2016. The Numaligarh refinery capacity is also planned to be raised, to 9 million t/a.

EGYPT

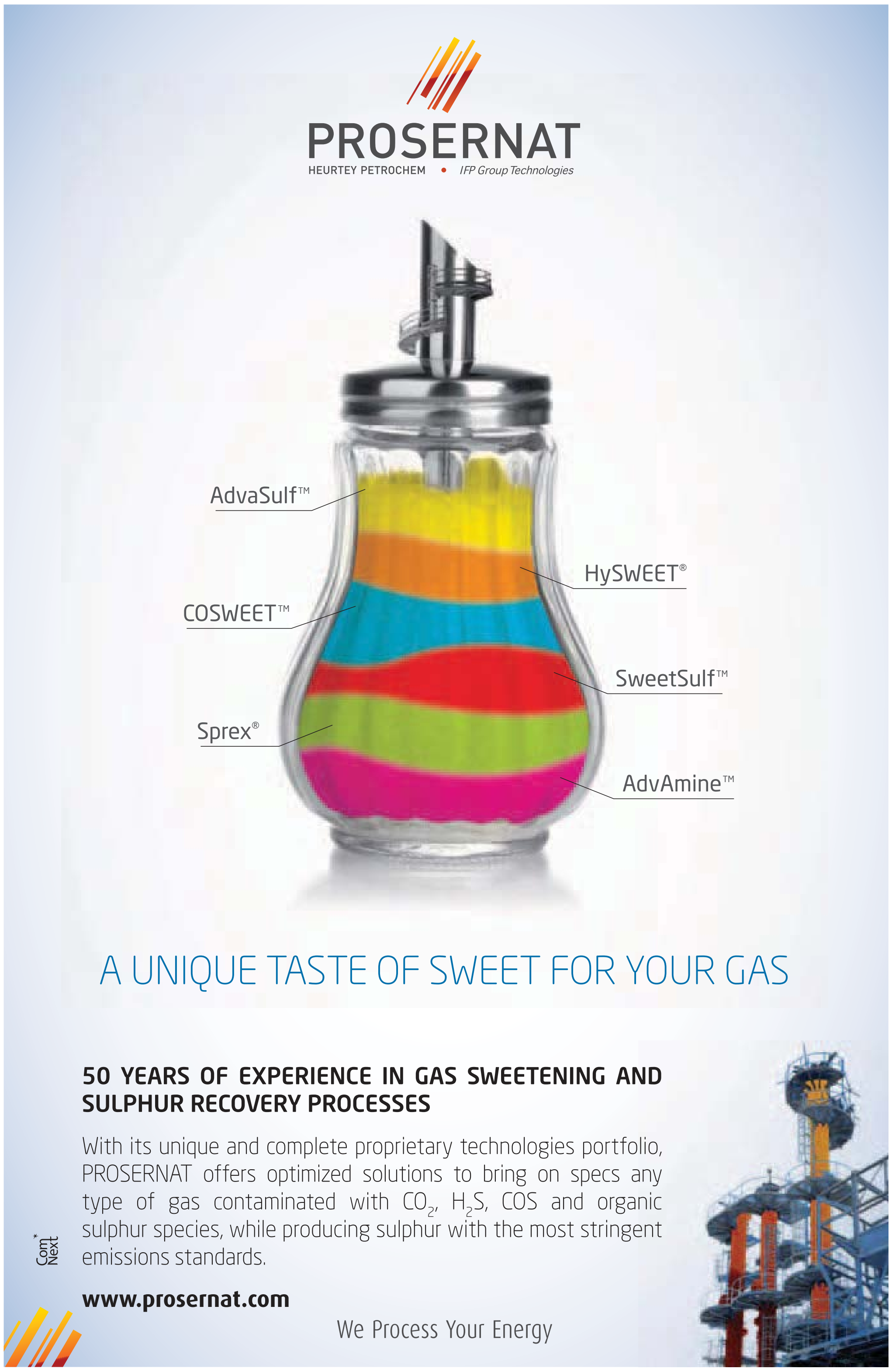
Technip to expand MIDOR refinery

Technip Italy SpA says that it has finalised a joint agreement with the Middle East Oil Refinery (MIDOR) to modernise and expand the MIDOR refinery near Alexandria. The investment has an estimated total value of $1.4 billion and aims at increasing its refining capacity from 100,000 bbl/d to 160,000 bbl/d. Export credit agency SACE, which was also a party to the agreement, has commited to launching the evaluation process in order to ensure an export credit facility to support the project. Technip will begin design engineering work in parallel with this and in due course will take responsibility for the EPC phase of the project. Technip has also recently received a contract to modernise the Assiut refinery in a joint agreement with the Egyptian General Petroleum Corporation and Assiut Oil Refining Company.

KAZAKHSTAN

Kashagan still aiming for late 2016

Kazakhstan still plans to resume commercial oil and gas processing at the idled Kashagan field in the Caspian Sea before the end of 2016, according to the country's deputy energy minister Uzakbai Karabalin. The field was shut in after hydrogen sulphide corroded the gas pipelines running to the onshore processing plant, forcing their replacement. A recent statement by the energy ministry reported that 99km of pipes have been produced in Germany and Japan, of which 67.5km of pipes have been delivered to Kazakhstan and 26km of these have already been re-laid. A total of 200km of pipeline must be replaced. Reserves at Kashagan are estimated at 38 billion barrels of oil in place, of which 10 billion barrels are recoverable, as well as 1 trillion cubic metres of associated highly sour gas.



Sulphuric Acid News

CHILE

Antucoya delayed into 3Q

Chilean miner Antofagasta says that delays in commissioning its Antucoya copper project are likely to reduce copper production and sulphuric acid consumption this year. Antofogasta reported 303,000 tonnes of copper production in 1H 2015, 12.9% down from the same period for 2014 and lower than forecasts, and the company's projection for full year production is now down to 665,000 t from 695,000 t. The company has faced issues with declining ore grades, unseasonal torrential downpours in the deserts of northern Chile and environmental protests which hit 1Q 2015 output to the tune of around 15,000 t.

Chief Executive Diego Hernández said in a statement that construction of Antucoya was completed on budget, but the company has experienced commissioning issues on the crusher circuit which means that first production will now be delayed to 3Q 2015. The greenfield Antucoya project is intended to compensate for ageing mines and declining copper grades elsewhere.

Output issues at Caserones

Japan's largest copper smelter Pan Pacific Copper, co-owned by JX Holdings and Mitsui Mining & Smelting, has faced output issues at its new Caserones mine and concentrate plant, which came on-stream in May 2014. However, Pan Pacific claims that the mine will still reach its full capacity of 150,000 t/a in the coming months. The slow ramp up of output has reportedly been due to issues with ore processing equipment and tailings dam system and inexperience among the workforce. Caserones ran at 70% capacity in July, but Pan Pacific said this will reach a notional 100% from September. Chile's state copper commmission Cochilco has twice downgraded its natinoal 2015 output forecast, which now stands at 5.88 million t/a.

NAMIBIA

Bannerman reports successful leach trial

Uranium miner Bannerman Resources says that it has successfully commisioned its Etango heap leach demonstration plant and completed the first phase of the demonstration plant programme. The results back up assumptions and projections from the definitive feasibility study, according to the company, including fast, high and uniform leach extraction of 93-94% in 20 days in a 120 t sample, with low sulphuric acid consumption (on average less than 16 kg/t compared with a projected consumption of 18 kg/t).

"The company has made significant progress during the quarter with the successful commissioning of the heap leach demonstration plant and the announcement of the exciting results from Phase 1 which strongly support the assumptions and projections incorporated in the DFS. Post quarter end we commenced Phase 2 which aims to replicate the results in Phase 1," said Bannerman's CEO, Len Jubber. "Further, the project optimisation work on the resource modelling and mine planning aspects of the DFS is progressing well and it is anticipated that updated mineral resource and ore reserves estimates will be released by the end of the December 2015 quarter. The Etango project continues to progress and remains one of the very few globally significant uranium projects that can realistically be brought into production in the medium term. The heap leach demonstration plant programme further derisks the Etango development path and will assist Bannerman to attract JV/funding partners."

Commmissioning begins for Tsumeb smelter

At the same time, a potential source of acid for Bannerman is in its start-up and commissioning phase. The Tsumeb smelter, operated by Dundee Precious Metals, has completed the construciton of an off-gas based sulphuric acid plant, designed by Outotec, to reduce sulphur dioxide emissions from the site, which has been operating since 1963. Based on an expected throughput of 240-310,000 t/a of copper concentrate, the acid plant will produce approximately 270-340,000 t/a of sulphuric acid.

"We have taken a giant leap forward in our continuing effort to upgrade the Tsumeb smelter and turn it into a world-class operation," said Dundee Precious Metals Tsumeb Vice-President and General Manager, Hans Nolte. Commissioning began in August, and commercial production is expected to begin around the start of 2016. Dundee has entered into a memorandum of understanding with Protea Chemicals Namibia to assist with the marketing and sales of the sulphuric acid that will be produced at the smelter.

Phosphate uncertainty continues

On the other hand, another potential customer for Tsumeb faces continued uncertainty, as the Namibian government debates whether to allow seabed phosphate mining to proceed after the expiry of an 18-month moratorium. Namibia banned phosphate mining in 2013 pending an environmental study but since the moratorium expired in March, there has not been any news about the way forward from government. A technical team comprising permanent secretaries from several ministries to look into the matter failed to meet two months ago to make recommendations on the way forward. The February 2015 ban by New Zealand on offshore phosphate mining by Chatham Rock Phosphates has also been a factor in prolonging the uncertainty – Chatham Rock is also one of the companies seeking offshore licences for Namibia. The Namibian Mining Ministry is said to be in favour of the proposal, but the Fisheries and Environment Ministries are against or uncertain.

SOUTH AFRICA

Montero moves to pre-feasibility study

Canadian mining company Montero Mining & Exploration has received an updated technical report and preliminary impact assessment of its integrated Saldhana Bay phosphate project on the west coast of South Africa. Montero is working with local South African company Ovation Capitol, which has expertise in mining and environment studies, to fund the development of the phosphate rock mines, which will be used to provide raw materials for a nearby projected phosphoric acid facility in Saldhana Bay. Mining services company DRA Global conducted the updated review, which supplements the original technical

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report and impact assessement undertaken in 2012. Overall, the report indicates favourable project economics, subject to caveats around phosphate rock prices and exchange rate fluctuations. The next step of the project will be to provide more detailed analysis of these parameters via a pre-feasibility study to be completed by Ovation, followed by a bankable feasibility study, the latter earmarked for the end of 2016.

CHINA

Commerical reference for solid acid alkylation technology

Luoyang Refining Aoyou Chemical Co., Ltd has signed a technical agreement with KBR to construct a 100,000 t/a solid acid alkylation project based on KBR's updated technology, with a projected investment cost of CNY 80 million ($12.5 million). The project is scheduled to complete construction by the end of 2016, and to start production in early 2017. KBR says that its solid acid alkylation technology has not been commercialised in China before. Compared with a conventional sulfuric acid alkylation process, the alkylate production rate of this technology could be significantly increased to a maximum of 80%, with additional benefits such as significantly reduced pollutants, high efficiency, low investment, and low operation costs, according to the company.

Located in Jili District, Luoyang, Henan Province, Luoyang Refining operates a 300,000 t/a light hydrocarbon deep processing plant, which now aims to take advantages of C4 olefins and isobutane to produce alkylate with a high octane number.

CANADA

Potash Ridge acquires SOP project

Potash Ridge Corporation has acquired all of the issued and outstanding common shares of Quebec-based Valleyfield Fertilizer Corporation, which over the past two years has advanced development of a potassium sulphate (sulphate of potash or 'SOP') project in Quebec using the Mannheim Process.

Under the terms of the transaction, Velleyfield's owner and president Jay Hussey will receive 200,000 shares of the new corporation, together with a royalty from future revenue generated. Mr. Hussey has agreed to become an employee of Potash Ridge and continue to work on the development of the Valleyfield Project, as well as other potential Mannheim Process opportunities already identified.

The Mannheim Process, developed in Germany a century ago, is one of the most commonly-used SOP production processes in the world, primarily in China and Europe. The process combines muriate of potash (potassium chloride) with sulphuric acid at high temperatures to produce SOP and by-product hydrochloric acid. Migao in China has 360,000 t/a of SOP production from four facilities using the process, and Tessanderlo, Yara and other European producers a combined SOP production capacity of 930,000 t/a.

Potash Ridge says that construction of the Quebec facility could commence within six months of raising the capital necessary to complete engineering and permitting, with construction expected to take one year. A fully-serviced property has been chosen to develop the Valleyfield Project, close to sources of input sulphuric acid as well as being nearby to markets for by-product hydrochloric acid. A memorandum of understanding has been signed for the offtake of the hydrochloric acid.

Potash Ridge's President and CEO Guy Bentinck, said; "acquiring Valleyfield brings a new dimension to the Corporation's strategy of becoming a premier producer of SOP. While we remain committed to the development of Blawn Mountain in Utah, the Valleyfield Project will allow Potash Ridge to become a producer of SOP in an accelerated timeline and at a very manageable capital cost. The Valleyfield Project is also strategically located to supply SOP to currently underserved markets in North America."

Outotec buys Kovit Engineering

Outotec has acquired Canadian-based Kovit Engineering Ltd from its founders. Kovit is a leading technical consulting and engineering company specialising in surface and underground mine tailings solutions. Outotec says that the acquisition will complement their existing de-watering and tailings treatment solutions and services, as well as strengthening their position as a global provider of sustainable tailings management solutions. The parties have agreed not to disclose the acquisition price.

Kovit Engineering's annual sales are some $5-10 million and its approximately 30 specialists in Sudbury, Canada, will transfer to Outotec.

"Effective and safe disposal of mining wastes presents technical and environmental challenges. This acquisition of Kovit Engineering will further strengthen our position as a provider of sustainable and water-efficient tailings management solutions to the mining industry", says Outotec CEO Pertti Korhonen.

Converters in place for Clean AER project

Three 100-t, 14 m long and 4.2 m diameter converters have been delivered to Vale's Copper Cliff smelter as part of the company's $1 billion Clean AER Project. The converters were fabricated in Sudbury by local engineering firm Anmar.The Clean Atmospheric Emissions Reduction (AER) project will reduce sulphur dioxide emissions from the smelter by 85% and greenhouse gas emissions by 40%, as well as lowering dust and metals emissions a further 35-40%, according to Vale. The project involves a complete retrofit of the converter aisle in the Copper Cliff Smelter. Sulphur dioxide that currently goes up the 'super stack' from the converters will be captured in a new wet gas cleaning plant and sent to the acid plant, converted to sulphuric acid and sold.

INDONESIA

Month long outage at Gresik

Indonesia's 300,000 t/a Gresik copper smelter in east Java was shut down for over a month between early July and mid-August due to technical issues. According to press reports, the facility faced problems with the cooling water system due to broken piping. P.T. Smelting is 60% owned by Japan's Mitsubishi Materials Corporation, with Freeport McMoRan's Indonesian subsidiary holding a 25% stake. Mitsubishi Unimental and Nippon Mining and Metal Co are also both minority shreholders.

UNITED STATES

Construction nearing completion on coal gasification plant

The long-delayed $6 billion coal gasification and carbon capture project at Mississippi Power Co.'s Kemper County energy facility is nearing completion. Major construction is finished, and work crews are now beginning the long testing and commissioning process which aims to see the facility up and running, producing 582 MW

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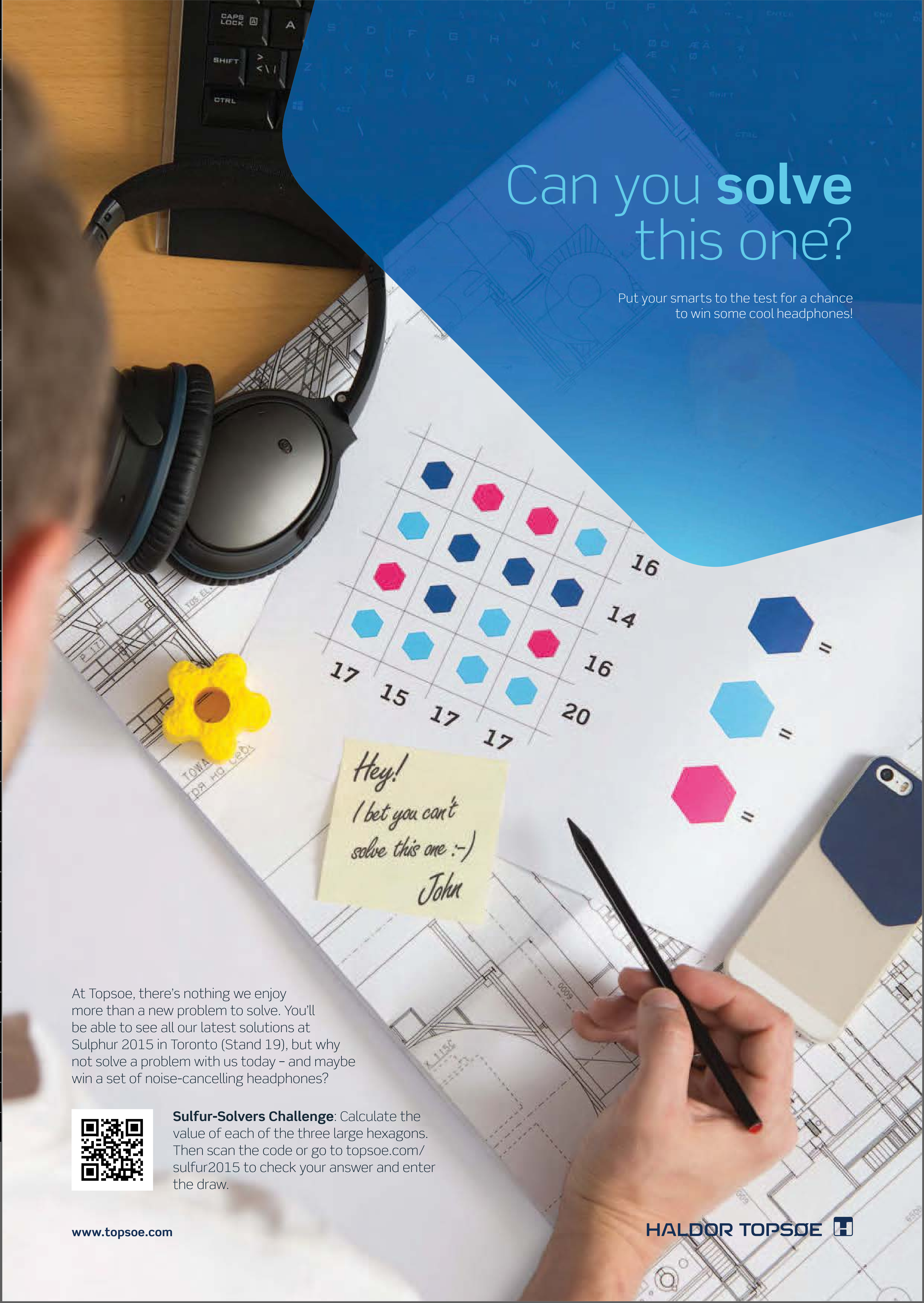
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SensoTech's sonic velocity flow meters.

of by the end of the 1H 2016. As well as the coal gasification to power plant, the complex features an ammonia side stream from the syngas generated by the gasifier, while sulphur removed from the syngas will feed a 135,000 t/a Topsoe wet sulphuric acid (WSA) plant at the site. Designed as part of the Bush 'Clean Coal' initiative, Kemper will also capture 65% of its carbon dioxide emissions.

Measuring acid and oleum strength using sonic velocity meters

SensoTech has launched a new sonic analyser which is able to monitor sulphuric acid and oleum strength in-line, directly in the process, using sonic velocity measurement. The company says that this can enhance the safety and efficiency of production plants, as the measuring results are available online and in real time. The *LiquiSonic*® analyser by SensoTech precisely measures with only one single sensor sulphuric acid and oleum strength in the relevant concentration ranges, with an accuracy of up to 0.03 wt%. If the measuring values exceed or fall below critical process thresholds, a signal will be sent immediately ensuring timely countermeasures can be initiated. The real-time information significantly increases work environment safety and product quality and reduces costs caused by acid wastage and failed production.

Made of Hastelloy C-2000, the sensor is absolutely resistant to corrosion. Construction requires neither gaskets nor moving parts, so the sensor is maintenance-free with long-term stability. Installation is conducted directly into the existing pipe or vessel. The measuring results are updated every second, and for process automation real-time data can be transferred to process control systems via 4-20 mA signal, digital outputs, fieldbus or Ethernet. The controller displays and saves the measuring values. The analyser is delivered as 'plug and play' system.

The company sees applications of the analyser in sulphuric acid production, alkylation, oil refining, syngas drying, fertilizer manufacturing, and the mineral processing industries, as well as etching and pickling baths.

Freeport looking at job cuts

Freeport-McMoRan is said to be reviewing costs in the light of the current run of low prices for metals, especially copper, and may be forced to make layoffs at is Tyrone and Chino mine operations in Arizona, which currently employ around 1,600 people. Freeport-McMoRan is the world's largest publicly traded copper producer, and the Chino open pit mine includes a 36,000 t/d concentrator that produces copper and molybdenum concentrates and a 70,000 t/a solvent extraction/electrowinning (SX/EW) plant which produces copper cathode from acidified solution. Tyrone operates a 45,000 t/a SX/EW facility. Chino and Tyrone both produce relatively low-grade copper ores, according to Freeport.

Cardero in restructuring to develop copper leach project

Canadian metals and minerals firm Cardero Resource says it is engaged in a comprehensive restructuring plan, which will involve the rescheduling of $8.5 million of debt, the sale of its subsidiary Cardero Coal (while retaining a participation right in the Carbon Creek coal project), and the acquisition of the Zonia copper project in Arizona. The company will also exchange old shares for new ones on a 10 for 1 basis, and undertake a $1.5 million private placement at $0.15/share.

Zonia has measured and indicated resources of 200,000 tonnes of copper, grading 0.33% at a 0.18% cutoff. The deposit had undergone deep oxidation from surface and metallurgical studies and has been demonstrated to be amenable to open pit mining, heap-leaching, and SX/EW to produce cathode copper, with an overall expected recovery of 73%.

AUSTRALIA

More job cuts for BHP Billiton

BHP Billiton has announced a third round of job cuts at its massive South Australian copper mine Olympic Dam, with another 380 positions to go due to poor copper market conditions. The layoffs are in addition to 360 cuts already announced at the company's Adelaide HQ and staff and contractors at Olymic Dam. The company has already taken a $200 million charge for redundancies at its Escondida project in Chile. The work force at Olympic Dam will overall be slimmed from 4,000 to 3,500 positions by the end of September. Copper production is expected to fall 12% for FY2015 compared with the previous year, dur to lower grades of ore, but BHP says it expects its copper business to return to growth in FY2017, and indicates that it is looking at cheaper heap leaching techniques to expand production at Olympic Dam.

BRAZIL

Cash raised for Tres Estradas feasibility study

Aguia Resources has raised $9.5 million to fund a bankable feasibility study for its Tes Estradas phosphate project. The preliminary economic assessment indicates that the project could deliver a net present value of $273 million and an internal rate of return of 25%. The size of the project has also been uprated from 350,000 t/a of single superphosphate (SSP) to 500,000 t/a of SSP, while projected capital costs fhave reduced from $218 million to $184 million. The project is estimated to have a mine life of some 15.5-years, based on a 70.1 million-tonne mineral resource.

Aguia managing director and chairman Justin Reid says that the company plans to initiate drilling at the nearby Joca Tavares deposit that has the potential to contribute additional high-grade oxide material, which will substantially improve the project's economics, and that Aguia is considering options to optimise production scales and mine life.

Reid also added that Aguia also expects to commence a drilling programmes at Cerro Preto in the coming weeks, where sediment hosted phosphate bears "striking similarities" to highly productive phosphate deposits in Idaho, and which are expected to add "considerable value" to the company before the end of 2015.

RUSSIA

DuPont holds acid emissions technology seminar

Around 40 managers from the sulphuric acid industry in the CIS came together in early June to discuss their views on sulphuric acid emissions reduction at a symposium held by DuPont and MECS in early June. The aim of the event was to gain the latest intelligence on new technology, operations and equipment. Participants were focused on sharing information and evaluating the latest technological developments for SO_2 emissions reduction and their impact on improving plant profitability and productivity, as well as on reducing operating costs.

"This symposium is part of a series of events we are holding throughout the world to track and compare international, national and local developments and needs in the sulphuric acid industry," said Thierry Marin, EMEA Clean Technologies Director, DuPont and Managing Director of MECS Europe/Africa. "With polling at each event, we are gaining a representative global picture of the industry. Following a very successful event at Sulphur 2014 in Paris last November, we are now in the process of organising similar events in Latin America and India."

Polling of the delegates at the DuPont MECS St Petersburg symposium showed that just over half the attendants saw SO_2 emissions as a limiting factor for production in their companies. However, it was not only the SO_2 emissions the majority of the managers were concerned about, but also SO_3 and H_2SO_4 emissions. The first priority for most in improving overall emissions performance was retiring old and inefficient assets and building new state-of-the-art plants, while a significant proportion also cited the need to revise procedures and upgrade equipment to minimise emissions, particularly during start-up, shutdown and malfunctions. Preference for tail gas (scrubbing) or enhanced sulphur recovery (improved catalyst conversion) as a solution to emissions control was equally split.

On the second day of the event, delegates went on a plant tour of mineral fertiliser company LLC Ig Phosphorit, part of EuroChem Group, to view its modern MECS SB sulphuric acid plant with *HRS*™ system, and share operational knowledge.

This symposium is part of a series of events DuPont MECS is holding around the world in 2015 and follows similar meetings held in Paris in November 2014, Mumbai, India in January 2015, and Uberaba, Brazil in June 2015. The next events will be held in Ndola, Zambia in the last week of October and in Mexico in 2016.

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47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84

People

Kimberly Gustin has become Phosphate Research Manager for Integer. According to the company she will also contribute to the company's sulphur and sulphuric acid research. Previously with CRU, Kimberly has five years' experience managing research teams and tracking sulphur and phosphate markets, as well as managing bespoke consulting projects covering a range of fertilizer-related subjects such as market entry and feasibility.

Environmental oilfield services provider Questor Technology Inc. has announced that **Susan J. Senn** has been appointed as the company's interim Chief Financial Officer and corporate secretary effective from July 27th, 2015. Mrs. Senn has over 30 years of experience leading finance teams, most recently, as Chief Financial Officer for Global Public Affairs Inc., Canada's largest privately held, fully integrated public affairs firm. Mrs. Senn holds a CPA, CA designation. She is a member of the CPA Canada Financial Literacy Western Advisory Board.

Ms. Mascarenhas, President and Chief Executive Officer, said, "Susan is a strong leader with a solid background and we are delighted that she has taken on the role of Interim CFO." Mrs Senn will serve in her role as the company continues its search for a long term strategic CFO to assist in the growth of the company.

Steve Langley.

H.J. Baker has announced that **Steve Langley** has joined the company's Crop Performance Division and Animal Health and Nutrition Division to accelerate its global growth initiatives. Langley brings more than 30 years of international business expertise in agriculture manufacturing and marketing to the company. For the last five years, he has focused on the swine and poultry equipment industry where he was the vice president of business development for QC Supply Inc. and ran the swine management systems for North America for Big Dutchman, Inc. out of Holland, Michigan. He also spent more than 14 years working in Shanghai, China as a sales and marketing executive and then COO of the China Premium Food Corporation. During his China tenure, he was also the founder and president of the North American Agri-Business International, which played a significant role in helping US and European companies develop and establish successful market entry into China. Langley serves on several boards as chairman and director for both US and Chinese companies. As Director of International Sales and Export, Langley will oversee all of H.J. Baker's international sales and marketing activities. He will be based in Kansas City, MO.

"Steve's depth of international experience and success in the agriculture industry make him a true asset for H.J. Baker," said executive vice president of sales and marketing Steve Azzarello. "Having Steve join us as Director is only going to help us as we move forward in our efforts to grow internationally."

Calendar 2015/2016

SEPTEMBER

21-23
IFA Production and International Trade Conference, TAMPA, Florida, USA
Contact: IFA Conference Service,
28 rue Marbeuf, 75008 Paris, France
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

OCTOBER

18-20
2nd Annual Middle East Sulphur Plant Operations Network (MESPON) Forum, ABU DHABI, UAE
Contact: UniverSUL Consulting,
PO Box 109760, Abu Dhabi, UAE
Tel: +971 2 645 0141
Email: info@universulphur.com

NOVEMBER

9-12
Sulphur 2015,
TORONTO, Canada
Contact: CRU Events
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

17-19
European Refining Technology Conference, ROME, Italy
Contact: Eliot Morton, GT Forum
Tel: +44 20 7316 9832
Email: eliot.morton@gtforum.com

JANUARY 2016

27
ASRL Chalk Talks and Poster Session, CALGARY, Canada
Contact: ASRL, University of Calgary,
Alberta T2L 2K8 Canada
Tel: +1 403 220 5346
Fax: +1 403 284 2054
Email: asrinfo@ucalgary.ca

FEBRUARY

21-24
66th Laurance Reid Annual Gas Conditioning Conference,
NORMAN, Oklahoma, USA
Contact: Betty Kettman
University of Oklahoma
Tel: +1 403 325 3136
Email: bettyk@ou.edu

MARCH

13-15
Phosphates 2016, PARIS, France
Contact: CRU Events
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

20-22
AFPM Annual Meeting,
DALLAS, Texas, USA
Contact: Yvette Brooks
Email: ybrooks@afpm.org
Web: www.afpm.org

20-24
SOGAT 2015, ABU DHABI, UAE
Contact: Dr Nick Coles, Dome Exhibitions
Tel: +971 2 674 4040
Email: nick@domeexhibitions.com

APRIL

11-13
TSI World Sulphur Symposium,
VANCOUVER, Canada
Tel: +1 202 331 9660
Email: sulphur@sulphurinstitute.org
Web: www.tsi.org

Jeffrey J. Bolebruch Senior Market Manager

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47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84

SULPHUR 2015

The Sulphur 2015 Conference and Exhibition will be held at the Sheraton Centre, Toronto, Canada, from November 9th – 12th.

The Sulphur Conference and Exhibition returns to Canada, one of the world's primary markets for the production, processing, transportation and trade of sulphur and sulphuric acid, with Toronto being a key hub for project finance and logistics. Its proximity to the sulphuric acid sector in Ontario and key US production sites make it an ideal setting for the global sulphur and acid community to meet and discuss the commercial and technical issues set to shape the industry. The Sulphur conference celebrated its 30th outing last year in Paris, attracting over 600 delegates from 43 countries, making it one of the biggest gatherings in the event's history.

As usual, the programme covers key market trends, project updates and supply and demand forecasts in the commercial sessions, with the two day split stream technical programme showcasing the latest technological developments to improve efficiency and compliance, and provides a forum for engineers from the sulphur and sulphuric acid industries to share experiences and develop solutions to common operational problems.

PROGRAMME

MONDAY 9 NOVEMBER

08:30 – 13:30	**Pre-conference site visit hosted by Chemetics**
09:00 – 13:00	**Workshop: Gas treating** in partnership with Optimised Gas Treating
14:00 – 18:00	**Workshop: Strategic options for sulphur producers and consumers in a surplus sulphur market** in partnership with Devco
14:00 – 17:30	**Workshop: Intelligent investments in your operations – CAPEX/OPEX optimisation while enhancing assets** in partnership with SNC Lavalin
13:00 – 20:00	**Registration desk open**
15:00 – 20:00	**Exhibition open**
18:00 – 20:00	**Welcome reception**

TUESDAY 10 NOVEMBER

08:00 – 18:00	**Registration desk and exhibition open**
09:00 – 17:30	**Commercial programme**
18:00 – 20:00	**Drinks reception**
08:55	**Welcome address** Mike Gallagher, CRU
09:00	**GLOBAL OUTLOOKS**
	Global oil and gas outlook Patricia Mohr, Scotiabank
	Global sulphur outlook Dr Peter Harrison, CRU
	Global acid outlook Thierry Tran, CRU
10:30 – 11:15	**BREAK**
11:15	**SULPHUR AND DEMAND UPDATES**
	Phosphate market fundamentals Youssef Bouslikhane, OCP
	Regional outlook for southern Africa – the metal producers' curse Steve Sackett, TradeCorp Chemicals
	China outlook – supply and demand Isaac Zhao, CRU
12:30 – 14:30	**LUNCH**
14:30	**PROJECT UPDATES**
	Sulphur project outlook
	Update on Mosaic's sulphur melter project Mark Gilbreath, Devco
15:30 – 16:00	**BREAK**
16:00	**SULPHUR LOGISTICS AND DEMAND**
	Updates on the dry cargo freight market Marc Pauchet, Braemar ACM Shipping
	Sulphur as a fertilizer
	Agronomic benefits of sulphur Don Messick, The Sulphur Institute

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WEDNESDAY 11 NOVEMBER

08:00 – 18:00 Registration desk and exhibition open

09:00 – 18:00 Technical programme

STREAM A: SULPHUR

09:00 **SULPHUR HANDLING AND SULPHUR VS CARBON EMISSIONS**

Strategic options for sulphur producers and consumers in a sulphur surplus market
Uday Parekh, Devco

Contaminated sulphur remelting
Andrew Rapal, Enersul

Dwindling sulphur emissions – at what cost?
Angela Slavens, UniverSUL Consulting
Kuppaswarmy Thiyagarajan, ADNOC

10:30 – 11:00 BREAK

11:00 **LEAN ACID GAS PROCESSING AND SMALL SCALE SULPHUR RECOVERY/REMOVAL**

Sour gas to profits
Tom Engert, Cameron Custom Process Systems

SmartSulf™ process in direct oxidation mode for very lean acid gas
Benoît Marès, Prosernat

The SOAP rocess
Simona Cortese, KT-Kinetics Technology

12:30 – 14:00 LUNCH

14:00 **SULPHURIC RECOVERY FROM FRONT END TO BACK END**

The seven deadly sins of sour water stripping
Ben Spooner, Amine Experts

Sulphur recovery unit integrated with dual-stage sour water stripper and incinerator section featuring ammonia destruction
Giuliano La Porta, Siirtec Nigi SpA

Effect of MMEA on the performance of tail gas units
Ralph Weiland, Optimised Gas Treating

15:30 – 16:00 BREAK

16:00 **SULPHUR DEGASSING AND CORROSION IN CLAUS SRUS**

Corrosion in Claus tail gas, sulphur pits and off-gas lines – where, how and why?
Peter Clark, ASRL

Shell pressurised sulphur degassing
Ries Janssen, Shell Global Solutions BV

New pre-pit sulphur degassing technology – 250 t/d validation unit testing results
James Hartman, Controls Southeast

STREAM B: SULPHURIC ACID

09:00 **METALLURGICAL ACID I**

Stabilisation and capacity increase of sulphuric acid plants and SRUs – use of skid-mounted burners for SO_2 supplementation
Andrés Mahecha-Botero, Noram Engineering

Novel design of WSA technology for smelter operations
Morten Thellefsen, Haldor Topsøe

Zambia's newest copper smelter and sulphuric acid plant
Bodrick Mumba, Kansanshi Mining
Stefan Mohsler, Outotec

10:30 – 11:00 BREAK

11:00 **METALLURGICAL ACID II**

Decreasing ore grades – how to maintain the acid quality
Karl-Heinz-Scherer, Outotec

Enhancing sulphuric acid production with Cansolv SO_2 and Bayqik technology
Laurent Thomas, Shell Cansolv

20 years of successful operation of a metallurgical acid plant at Southern Peru Copper Corp
Kleber Jurado, Southern Peru Copper Corp

12:30 – 14:00 LUNCH

14:00 **SULPHURIC ACID CATALYSTS**

BASF's sulphuric acid catalysts – new developments
Christine Schmitt, BASF

Increased productivity and lower emissions in sulphuric acid plants through Clariant's SulfoMax® EV catalyst
Michael Hinton, Clariant

Understanding dynamics and emissions during sulphuric acid converter startup
Kurt Christensen, Haldor Topsøe

15:30 – 16:00 BREAK

16:00 **SULPHURIC ACID WORKSHOP**

Turnaround planning

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THURSDAY 12 NOVEMBER

08:00 – 14:00 Registration desk and exhibition open

09:00 – 12:30 Technical programme

STREAM A: SULPHUR

09:00 GETTING THE TEMPERATURE RIGHT

Sulphur recovery unit heat maintenance
Frank Scheel, Jacobs Comprimo Sulfur Solutions

Advantages of 2-colour pyrometry in temperature measurement of the Claus reaction furnace
SJ Croom, Delta Controls

Temperature measurement in the modified Claus sulphur reactor
David Ducharme, LumaSence Technologies

10:30 – 11:00 BREAK

11:00 BURNER AND WASTE HEAT BOILER DESIGN

New developments in tubesheet protection
Mark Welters, Innalox

Examining the impact of waste heat boiler design and operation on reliability
Elmo Nasato, Nasato Consulting

Design challenges and solutions for acid gas burners and tail gas incinerators in SRU plants
Chris Onysko, Aecometric Corporation

12:30 LUNCH

STREAM B: SULPHURIC ACID

09:00 HEAT RECOVERY

Heat recovery – efficiency at any price?
Stefan Braeuner, Outotec

MECS® SolvR™ technology – a platform for the next generation of sulphuric acid technology
Jason Hartman, DuPont MECS

Thermodynamic analysis of a sulphur combustion turbine in a sulphuric acid plant
Robert Buckingham, University of San Diego

10:30 – 11:00 BREAK

11:00 SULPHURIC ACID OPERATIONS

Anodically protected stainless cooler vs alloy cooler – making an informed decision
Herbert Lee, Chemetics

Case studies in next generation furnace designs for sulphuric acid plants
Brian Lamb, MECS

Hydrogen incidents in sulphuric acid plants: why now? What can we do?
Leonard J Friedman, Acid Engineering & Consulting

12:30 LUNCH

Sulphuric acid in Europe

Europe's acid industry is mature, based heavily upon smelter acid production, and with a legacy of many industrial uses on the consumption side. It also remains a major exporter of acid to other regions.

Europe is one of the world's major sulphuric acid producers and exporters, accouting for about 10% of global acid production, with a long legacy of industrial production dating back to the industrial revolution. Although acid plants in some countries, like the UK, have mainly closed down as traditional heavy industries found it hard to compete with imports from the rest of the world, other traditional producers still maintain large capacities.

Acid production

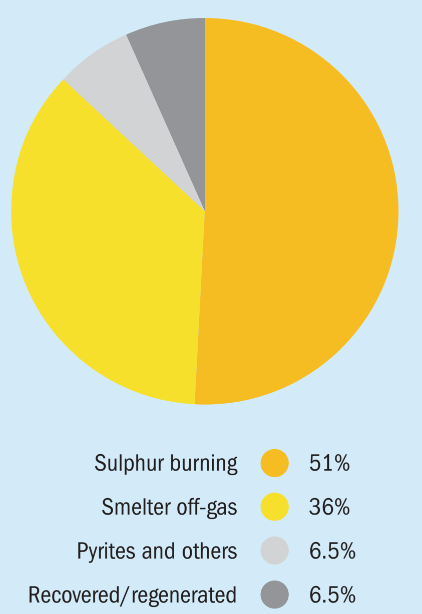
According to the European Sulphuric Acid Association (ESA), there were 94 sulphuric acid plants operational in Europe in 2014, with a total combined capacity of just over 26 million t/a. Among these, the largest national operator of acid capacity was Germany, with a total of 5 million t/a of sulphuric acid capacity, followed respectively by Poland (2.75 million t/a), Spain (2.28 million t/a), Belgium (2.24 million t/a), Finland (2.20 million t/a), Italy (1.84 million t/a) and Bulgaria (1.75 million t/a). These seven countries between them represent 70% of European sulphuric acid capacity. Sweden and France are also significant producers (about 1 million t/a each).

Smelting has been one of the traditional mainstays of European sulphuric acid production, although in fact only around 36% of Europe's acid capacity (9.5 million t/a) is based on smelter off-gas. Particularly notable producers include Aurubis in Hamburg and at Pirdop in Bulgaria (these two sites alone account for 3 million t/a of acid capacity), Atlantic Copper at Huelva, Spain, and two large Boliden smelters in Skellefteham, Sweden and Harjavalta, Finland. These five sites collectively represent 55% of European smelter acid capacity. In 2014, smelter production was running at 92% of capacity, and represented 45% of European acid production.

However, the most significant proportion of capacity is actually based on sulphur burning acid plants, which represent just over 50% of capacity (although only 40% of production). This capacity is concentrated in Germany, Belgium, Poland and Italy, which represent half of all sulphur burning capacity between them. There is also still some small pyrite-based capacity in Europe; about 1.7 million t/a, mostly in Germany and Finland, as well as around 1.7 million t/a of recovered and regenerated acid.

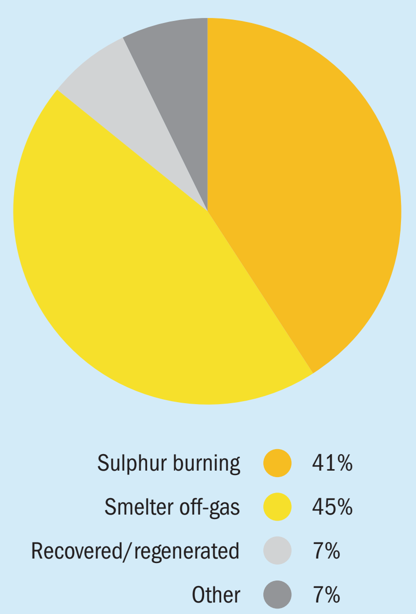
Total European acid production in 2013 was around 22 million t/a, representing just under 10% of global sulphuric acid.

Fig 1: European sulphuric acid capacity by type, 2014



Source: ESA

Fig 2: European sulphuric acid production by type, 2014



Source: ESA

Demand

Europe's demand for sulphuric acid rant at about 18 million t/a in 2013. About 20% of this goes towards fertilizer production, mainly phosphates, but this is a much lower proportion than in many other markets – Europe's sulphuric acid industry remains linked to its industrial production, as it has done for decades. Just over 60% of European acid demand is represented by chemical production, and of this percentage, the largest industrial use is titanium dioxide production. Titanium dioxide is a key whitener and opacity agent in paints, pigments and paper. There are broadly speaking two main production routes towards titanium dioxide – via a chloride route, pioneered by US companies – and a sulphate route. The sulphate route is the older and has been historically regarded as more polluting, but European producers have developed far cleaner systems which recycle spent acid. Although European consumption of acid for titanium dioxide manufacture has steadily fallen, by about 35% in the past 15 years, it still consumes over 3 million t/a of sulphuric acid.

Next down the list of chemical uses for acid in Europe is production of other acids, chiefly hydrochloric and hydrofluoric acids, but also including citric acid. These sectors represented another 2.8 million t/a of acid demand in 2013, while fibre manufacture, mostly caprolactam, but also including rayon, consumed another 2.4 million t/a. Methyl methacrylate, for acrylic sheeting and moulding components, used 1.6 million t/a of sulphuric acid in 2013. Other chemical uses include aluminium sulphate, mainly used in water treatment and pulp

1 47 2 48 3 49 4 50 5 51 6 52 7 53 8 54 9 55 10 56 11 57 12 58 13 59 14 60 15 61 16 62 17 63 18 64 19 65 20 66 21 67 22 68 23 69 24 70 25 71 26 72 27 73 28 74 29 75 30 76 31 77 32 78 33 79 34 80 35 81 36 82 37 83 38 84 39 40 41 42 43 44 45 46

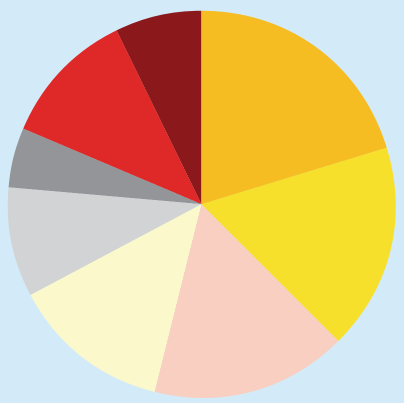
and paper manufacture. Finally, non-chemical industrial uses make up most of the remaining 20% of demand, such as metal treatment – leaching, steel pickling etc.

European demand for acid is largely mature, and although there are ups and downs due to the cyclical nature of many of the industries, there is no large-scale growth.

Exports

European acid production tends to run in excess of acid demand, to the tune of about 4 million t/a. European acid is sold in many different markets, including the US, Cuba, Brazil, Turkey, Morocco and as far afield as Namibia and Chile, but as noted by Fertecon's Janos Gal at ESA's June meeting in Malaga, there are changes in many of these import markets which may impact upon European sales of acid. In Morocco, OCP is in the process of massively expanding its phosphate capacity, but this will involve the construction of a large quantity of sulphur-burning acid capacity, which may reduce its demand for imported acid. Likewise Sherritt in Cuba, which imports 500,000 t/a of acid, almost all of it from Europe, is building a new sulphur burning acid plant for its nickel leaching operation, and although the plant has been several times delayed, it currently remains on track for completion in late 2016. Toros Agri in Turkey, which imports acid chiefly from Bulgaria, is also building a new sulphur burning acid plant which could reduce acid demand by 725,000 t/a. Additional Turkish demand could come from nickel heap leaching projects, but in the current nickel price environment these may face continued delays. Chile's acid needs are declining, and in this market Europe also faces stiff competition from Japan, South Korea and Peru. In Namibia, the start-up of the Tsumeb smelter acid plant will provide more than enough acid for domestic uranium leaching, and could shut out 135,000 t/a of European acid imports. Finally, declining US phosphate production could reduce demand there; a market which currently imports 3.2 million t/a of acid, mainly from Canada and Mexico, but also significant volumes from Europe. Again, copper leaching projects have the potential to increase longer term demand, but not in the immediate future.

Fig 3: **European sulphuric acid consumption by end use, 2014**



Source: ESA, IHS

Sulphur in fertilizers

Growing awareness of the issue of sulphur deficiency in soils is leading to the launch of new sulphur-containing fertilizers.

PHOTO: SOHAR SULPHUR FERTILIZERS LTD

Sulphur bentonite is an increasingly used sulphur fertilizer product

Sulphur's importance as a plant nutrient in its own right is becoming increasingly recognised, especially as controls on sulphur in fuels and scrubbing of sulphur oxides from power plant tail gas leads to steady reductions in 'free' sulphur deposition to soils. There had also been a reduction in the use of more traditional fertilizers like ammonium sulphate (AS) and single superphosphate (SSP) which also carried a 'free' sulphate component in favour of higher analysis fertilizers like urea and diammonium phosphate. However, since sulphur has started to become valued as a fertilizer in its own right, there has been something of a turnaround in use for both of these, while an increasing variety of new sulphur-containing products are now becoming available. As sulphur-containing enzymes play a key role in nitrogen fixation, sulphur's presence can enhance plant uptake of other nutrients, especially nitrogen, but also – in the correct quantity – of phosphorus availability. Sulphur can also help zinc uptake, and zinc deficiency is itself an increasingly recognised issue in various parts of the world.

The push for sulphur fertilizers has come initially from bodies such The Sulphur Institute, and more recently The Fertilizer Institute, which has identified sulphur as part of its '4Rs' nutrient stewardship programme (Right Source, Right Place, Right Time, Right Rate), and has also been taken up by recommendations from government bodies, and even found its way into labelling and subsidies in India's fertilizer subsidy programme. But increasingly it is fertilizer companies which have identified sulphur-containing fertilizers as a key product in their portfolio, and which are now developing products to meet the needs of an increasingly sophisticated fertilizer marketplace.

Sulphur vs sulphate

Sulphur can be delivered to soil in various forms, but the essential breakdown is in sulphur vs sulphate. Most fertilizers containing sulphur contain it in its oxidised, sulphate form – this is the case in ammonium sulphate and SSP, but also potassium sulphate (aka sulphate of potash – SOP), ammonium nitrate sulphate, calcium sulphate (gypsum), magnesium sulphate and zinc or iron sulphates. Thiosulphates like ammonium thiosulphate – $(NH_4)_2S_2O_3$ – operate in a similar way. In sulphate fertilizers the sulphur is in a form immediately digestible by the plant. Other fertilizers rely upon sulphur in its elemental form, as S_8, and require conversion to sulphate by thiobacillus bacteria in the soil. Sulphur conversion by thiobacillus requires moisture and oxygen (the top layer of soil must be well aerated) and the correct temperature range. In order to speed up sulphur availability from elemental sulphur it is often mixed with an agent which assists its dispersal, often a bentonite clay. In sulphur bentonite (marketed by H. J. Baker & Bro as *Tiger-Sul*), the sulphur is intimately mixed with bentonite clay in the ratio approximately 85-90% sulphur to 10-15% clay. The bentonite absorbs water, swelling and fracturing the granule/pastille and allowing a faster breakdown of sulphur by soil bacteria.

Sulphur demand

Recommended sulphur application to soil in Europe and North America is generally around 20-40lb/acre (22.5 – 45 kh/ha), although obviously this is soil and indeed crop dependent. Uptake of sulphur is about 10lbs/acre (11kg/ha) for wheat, but up to 40-50lbs/acre for tomatoes and peppers. Some plants such as oilseed rape have a very high sulphur demand (50-70kg/ha), and the same is true for palm oil cultivation.

In order to meet this demand, the traditional sulphur-based fertilizers are ammonium sulphate (AS) and single superphosphate (SSP), and they continue to claim around 75% of the market for sulphur-containing fertilizers. In 2013, use of ammonium sulphate amounted to 5.5 million tonnes S, according to IFA, while use of SSP was 3.1 million tonnes S. Use of potassium sulphate (SOP) was 0.9 million tonnes S, and magnesium sulphate about 350,000 tonnes S. Sulphur bentonite

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production and elemental sulphur direct use as a fertilizer total around a million tonnes S per year, including in sulphur enhanced urea, which uses the sulphur as a coating to delay the conversion of urea to nitrate, turning it into a delayed/controlled release fertilizer.

Ammonium sulphate is a by-product of a number of industrial processes, from caprolactam manufacture to stack gas scrubbing, and hence continues to be available at relatively low cost, while SSP is simple to manufacture from phosphate rock (merely by the addition of sulphuric acid), and, as we noted in our article earlier this year (*Sulphur* 356, Jan/Feb 2015), while consumption continues to fall in China, there has been a demand increase in India and Brazil, in the former case due to its relative ease and cheapness of manufacture compared to DAP, and in the latter precisely because of its sulphur content.

Expanding operations

Many major fertilizer manufacturers are now taking an increasing interest in production and marketing of sulphur containing fertilizers. Russia's EuroChem recently introduced a new compound fertilizer which it calls Sulphammophos, with a 20-20-13-5 NPKS ratio, intended for use in southern Russia where there has been a problem with sulphur deficiency in soils.

In February, also in Russia, PhosAgro commissioned a new phosphate-potash-sulphur fertilizer production line with a capacity of 100,000 t/a together with a finished goods warehouse with a 1,500 tonne capacity, at a total investment cost of 500 million rubles.

In the UK, Sirius Minerals gained permission this August to go ahead with developing the York Potash project underneath the North York Moors in the north of England. Here the deposit is polyhalite, a mix of potassium, magnesium and calcium sulphates with 19% sulphur content by weight. Sirius says that it intends to produce 1.5 million t/a of polyhalite, and has already secured an offtake agreement with "a major US agri-business company". The presence of the sulphur is, Sirius says, a key feature in the agronomic benefits of its own project compared to existing potash producers which it will compete against.

Qafco in Qatar is installing a high speed drum granulation pilot unit to develop various urea-based products by adding sulphur, ammonium sulphate and a diverse range of other micronutrients, which will be up and running by the end of 2015. Based on the experience from the pilot unit, larger capacity units for producing specialty urea will be installed to use the large quantities of sulphur now available from Qatar's LNG processing and other industries.

Earlier this year, H.J. Baker & Bro launched Tiger XP, a variant of its sulphur bentonite product using a proprietary activator to speed up the uptake of the sulphur. Using metal oxides in the mix creates a reactive acidic zone around the oxide particle when in the presence of thiobacillus-derived SO_4 which can make available to the plant zinc, iron, calcium and manganese sulphates.

And the US Department of Agriculture has recently published research which shows that application of gypsum – calcium sulphate – can reduce phosphorus run-off from soils by up to 50%, reducing algae growth in water channels.

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Tightening regulations on sulphur in fuels

Some of the boom in sulphur production over the past three decades has come from tightening regulations on sulphur content in vehicle fuels, but maritime and aviation fuels are now also coming under increasing scrutiny.

Fig 1: **Global standards on fuel sulphur levels in diesel, September 2007**

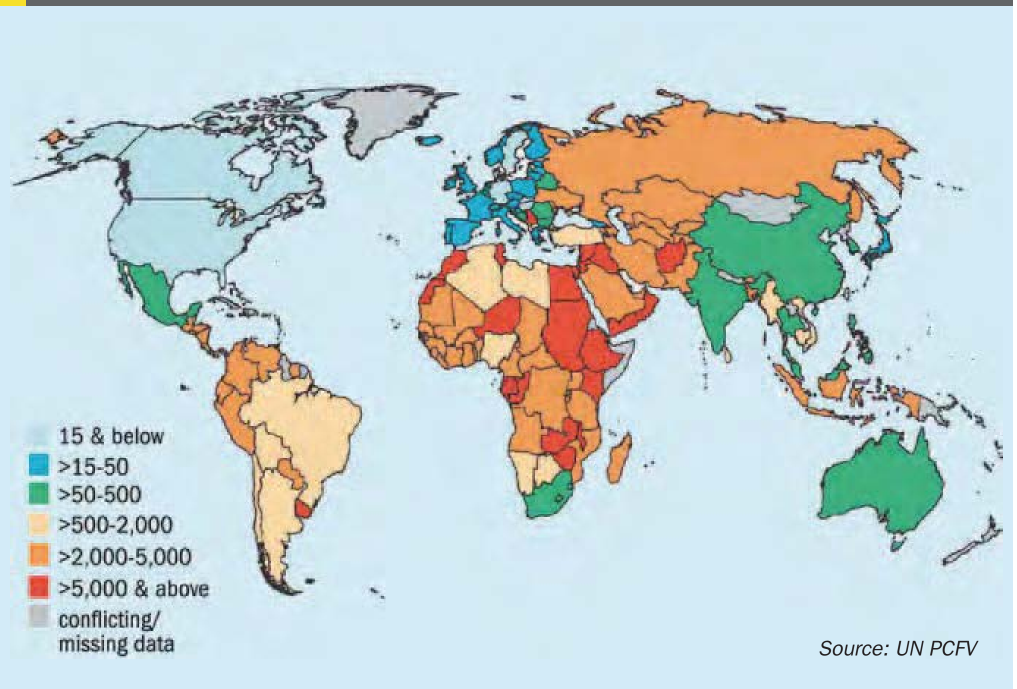
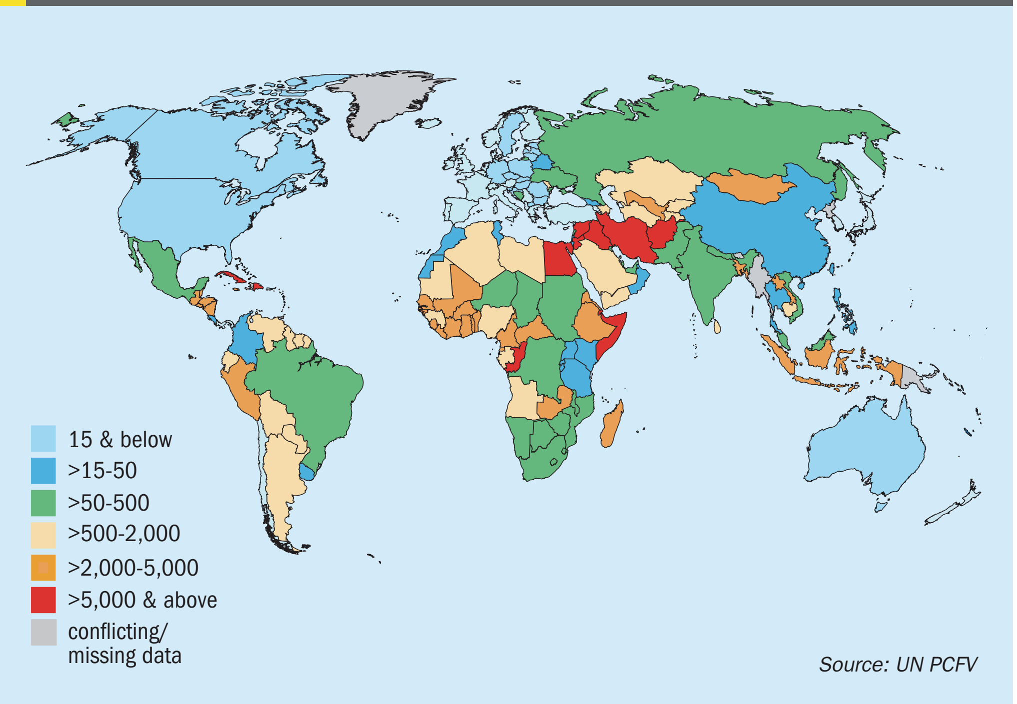


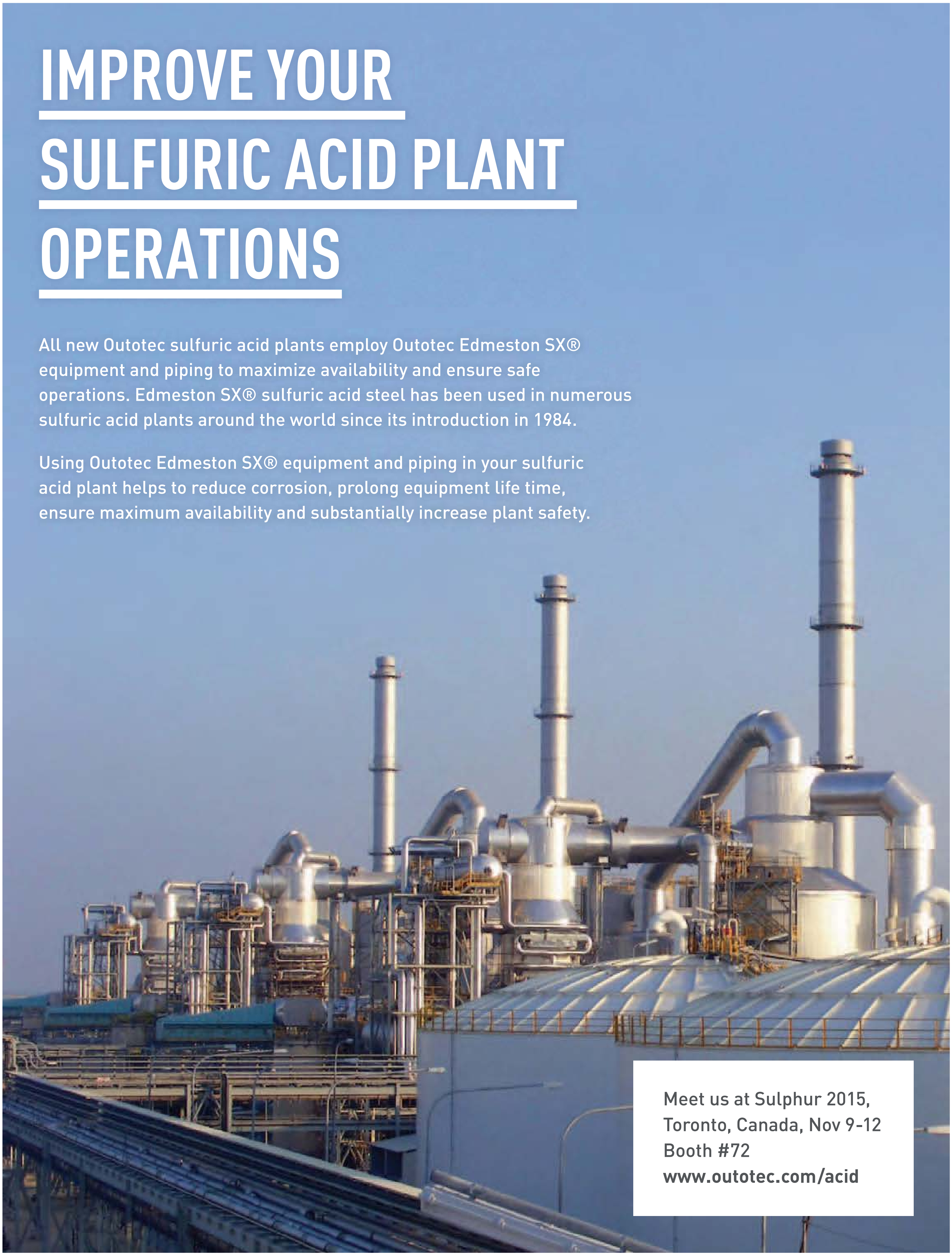
Fig 2: **Global standards on fuel sulphur levels in diesel, June 2015**



Global regulations on sulphur in fuel continue to tighten as a result of health concerns about sulphur dioxide and its link to respiratory illness, especially in urban areas in developing and industrialising countries. Lower levels of sulphur in fuels also allow for better clean-up of other pollutants. For example, sulphur fuel levels of 500 ppm and below (so-called 'Euro II') allows the use of diesel oxidation catalysts and retro-fits of older vehicles. Sulphur fuel levels of 50ppm and below ('Euro IV') allow the use of diesel particulate filters – of great importance now that particulate matter in diesel is recognised as a major pollutant in its own right. For gasoline vehicles, reducing sulphur levels to 500 ppm and below improves the performance of catalytic converter systems. This focus on SO_2 emission reduction and lower sulphur fuel levels is continuing to force continuing investment in sulphur recovery capacity at new and existing refineries worldwide, and generating millions of tonnes of additional sulphur to the market.

Road vehicles

For diesel and gasoline-fuelled vehicles, since 2002 the action has been coordinated via the UN Partnership for Clean Fuels and Vehicles (PCFV), a collaborative venture between governments, the private sector, non-governmental organisations, and international organisations. This global partnership aims at assisting developing and transition countries in reducing urban air pollution through the promotion of clean fuels and vehicles. Their initial focus was in fact the elimination of lead in petrol, but with that largely achieved, the main activity is now the phasing down of sulphur in diesel and



Sustainable use of
Earth's natural resources

Outotec

Table 1: Middle East and North African diesel sulphur content

Country	Diesel sulphur level (ppm)	Comment
Algeria	900	Plans to move to Euro III standards for both gasoline and diesel.
Bahrain (GCC)	500/10	Produces 10ppm for export demand. Local available is 500ppm.
Egypt	6-7,000	No plans to reduce levels, 2,000ppm fuel available.
Iran	5,000	Standard = 10,000 ppm.
Iraq	10,000	Standard = 25,000 ppm.
Israel	10	Follows EU standards.
Jordan	5,000	Standard = 12,000 ppm. 350ppm produced locally.
Kuwait (GCC)	500	Standard = 5,000 ppm. Clean fuels project delayed.
Libya	1,500	Standards = 10,000 ppm. 350ppm and 50ppm available.
Morocco	50	Effective January 2009.
Oman (GCC)	500	No update available.
Qatar (GCC)	500	Announced road map plans for 10ppm but postponed.
Saudi Arabia (GCC)	500	Moving to Euro-V standard across all refineries.
Tunisia	5,000	No update available.
UAE (GCC)	500	Standard = 5,000 ppm but moving to Euro-V.
Yemen	500	Mostly imports Euro II and IV from GCC countries.

Source: UN PCFV

petrol fuels, concurrent with the adoption of cleaner vehicles and vehicle technologies. At the fourth global PCFV meeting which took place in December 2005 in Nairobi, the PCFV partners collectively agreed to aim to reduce sulphur in vehicles fuels to 50 parts per million (ppm) or below worldwide.

The most recent global partners meeting occurred in 2014 in Paris, at which partners were informed that the sulphur reduction campaign was now gaining momentum and a total of 13 countries had reduced their sulphur levels to 50 ppm and below since the PCFV's formation in 2002. An additional five countries were set to lower sulphur to 50 ppm and below by the end of 2014, and many more countries had substantially reduced their sulphur levels in fuels from 2-3,000 ppm (or even higher) to 500 ppm. A map of the global changes for diesel between September 2007 and June 2015 (Figures 1 and 2) show how much progress has been made in just eight years. The UNEP says that it has used a regional approach to achieve country-level change, with a focus on the 'leading' countries within the regions. For example, this approach was used successfully in East Africa and the ASEAN regions – in East Africa, Kenya has moved from an average fuel content of more than 5,000 ppm sulphur to less than 50ppm. Many countries have now selected 10 ppm sulphur as their ultimate target, a standard now largely achieved in Europe, Japan, South Korea and Australasia, while the US and Canada operate a 15ppm (Euro V) standard.

Most notable for sulphur production levels has been China's move to a nationwide Euro-IV standard, and Eastern Europe's switch towards EU levels of fuel sulphur content. Russia moved to Euro-IV in 2013. India operates a Euro-IV standard for urban areas, but its green colouration in Figure 2 is indicative that a Euro-III standard (350ppm) applies elsewhere in the country. Brazil moved to a Euro-IV standard in January 2014. The main holdout region for lowering fuel sulphur standards, as Figure 2 shows, is the Middle East. Table 1 gives a listing of current sulphur levels in Middle Eastern countries. As can be seen, outside of Saudi Arabia and the UAE, there is no current plan to move towards stricter standards in most countries. China, the US and EU represent about 60% of all new vehicle sales, and so China's move to low sulphur emissions are likely to be the most important in terms of additional demand for low sulphur fuels – China alone accounted for 25% of all new vehicle sales in 2013. China has announced that it will move to a nationwide Euro-V standard by 2018, and the US will reach equivalent levels in 2017 for gasoline light duty vehicles.

Maritime fuels

Global sulphur standards for maritime fuels are set by the International Maritime Organisation (IMO). At the moment there are two sets of standards – one for so-called Emission Control Areas (ECAs) – mainly the Baltic and North Seas, the Caribbean, and the areas off the east and west coasts of the United States and parts of Canada – and one for all other areas. ECAs moved from a sulphur standard of 1% to 0.1% (1,000 ppm) as of January 1st 2015, while the global sulphur limit still currently stands at 3.5% (35,000 ppm). The global standard is due to drop to 0.5% (5,000 ppm) on either the 1st January 2020 or 2025, depending upon the results of a review of whether there is adequate fuel available to meet demand, and there is considerable disagreement about whether this will be the case or not. There were fears that the ECA regulation, which effectively mandates either the use of marine diesel/gas oil (MDO/MGO), a clean burning fuel like liquefied natural gas (LNG) or methanol, or the use of an expensive exhaust scrubbing system, would push up fuel costs to unsustainable levels. As of April 2015, however, MGO was trading at a reasonably manageable $140/t premium in Houston over high sulphur fuel oil (HSFO) – $590/t as compared to $450/t – and $200/t in Rotterdam ($510/t as compared to $310/t).

The global decline in the price of oil has eased shipping industry concerns about prohibitively expensive fuel, although many carriers are now charging a premium for transport in and out of ECAs. Use of seawater scrubbing systems has been dealt a further blow by upcoming IMO regulations on discharge of tanks and wastes to open water, and the use of completely enclosed scrubbing systems may push the cost up further. At the moment it seems to be LNG which has gained the greatest boost, and some shipping companies are looking to LNG to carry them past the global emission limit, whether it is imposed in 2020 or 2025, instead.

The Oil Companies International Marine Forum (OCIMF) and what was formerly known as the International Petroleum Industry Environmental Conservation Association (IPIECA) recently submitted a joint paper on the issue of fuel availability at the IMO's Marine Environment Protection Committee (MEPC) meeting, highlighting that projecting refinery capacity to meet global demand is a complex issue with many interdependent variables, and calling on the committee to consider the reaction of the market to decisions made by the global refining industry, and the limited flexibility of refineries to modify the range of products they make. The IMO's decision on whether or not to postpone the implantation of the 0.5% global limit is expected early next year.

Aviation fuels

At the moment there are no plans to introduce more stringent sulphur specifications for aviation fuels, which often average around 1,000 ppm sulphur. In 2010, the International Civil Aviation Organisation (ICAO) established stringent, but non-binding, NOx reduction targets that are equivalent to a 45% reduction by 2016, and a 60% reduction by 2026. In addition, ICAO is looking at a standard on particulate matter next year. However, evidence that sulphur and SO_2 aerosols at high altitudes actually help to mitigate global warming has been a key factor in decisions not to try and tackle this issue as yet, although many health bodies are nevertheless concerned about SO_2 emissions by aircraft in the vicinity of airports.

"At the moment it seems to be LNG which has gained the greatest boost, and some shipping companies are looking to LNG to carry them past the global emission limit.

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Airborne sulphur particulate in formed sulphur handling

Gerard d'Aquin, president of consultancy Con-Sul, Inc and publisher of the North American Quarterly Sulphur Review, discusses the causes of and mitigation of airborne sulphur particulate in formed sulphur handling.

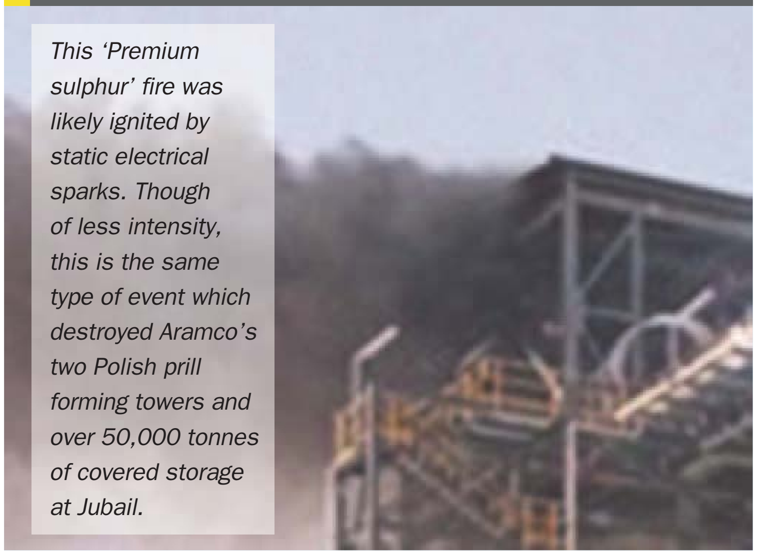
Vancouver was the perfect venue to host the IFA Global Safety Summit earlier this year, with its emphasis on Fertilizer Safety; volumes of potash, phosphate rock, sulphur, urea, ammonium sulphate and various finished fertilizers all transit through the port. In the 1970s and 1980s Vancouver was "sulphur supplier to the world" with shipments close to 7 million tonnes per year. Today, the volume of exports struggles to remain above 2.5 million t/a.

Public criticism of yellow dust clouds associated with shipments of crushed sulphur led to the eventual banning of such movements in 1972. This led to the development of various sulphur forming techniques. Scientists working for SUDIC (the Sulphur Development Institute of Canada), seeking a premium Canadian solution in the early 1970s developed guideline specifications for 'Premium' and 'Standard' material, which are described in Richard Hands' excellent article 'Mind the Gap' in *Sulphur 359*, Jan/Feb 2015. Readers are is encouraged to review this document as excellent background for this article.

The size specifications of Premium sulphur that was selected by SUDIC to develop future forming processes matched that of sulphur beads, or prills, produced by a traditional air-cooled forming process patented in Poland. Thus it became known as the 'Polish' or air prill process. Other processes and improvements came into use during the 1970s and early 1980s, their principal differentiation being whether cooling water came into direct contact with sulphur. Following the explosion at a Polish prilling facility at Jubail in Saudi Arabia in 1982 and operators'/governments' recognition of the technology's huge environmental impact, Polish prill units were gradually taken out of service. This leaves a clear divide between "wet" and "dry" sulphur forming processes based on whether cooling water comes in direct contact with sulphur, is used indirectly or in the form of steam.

The author has studied "sulphur dust" since 1983, having been involved in the early efforts to import formed sulphur to the US and in the development of the State of Florida's regulations regarding formed sulphur. The result has been several papers and presentations, of which this is the latest, focusing on 'volatile sulphur particulate', i.e.: sulphur particles which become airborne when sulphur is transported under normal conditions. Conclusions and comments herein are based on research and decades of on-site

Fig 1: **Airborne sulphur particulate can readilly ignite...**



This 'Premium sulphur' fire was likely ignited by static electrical sparks. Though of less intensity, this is the same type of event which destroyed Aramco's two Polish prill forming towers and over 50,000 tonnes of covered storage at Jubail.

Fig 2: **...causing explosions and fires at transfer points**

Airborne sulphur particulate emissions at a conveyor transfer point during the unloading of "Premium" sulphur, zero moisture, no sprays, very slight breeze.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46
47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84

Fig 3: **Particle sizes of three formed sulphur types at the manufacturing site**

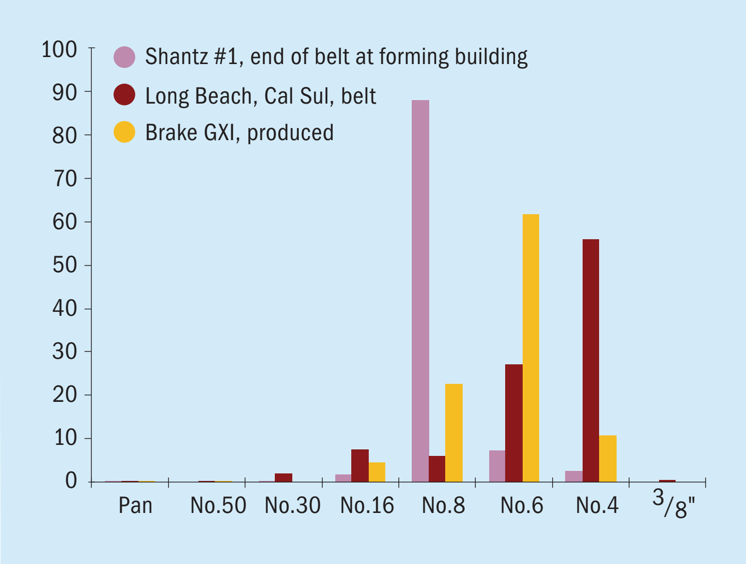
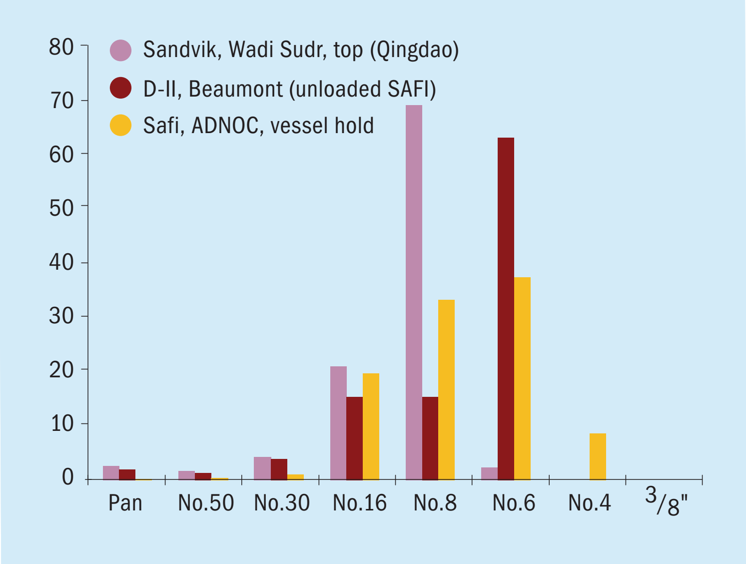


Fig 4: **Particle sizes of three formed sulphur types at destination**



observation and evaluation. In this context, experience and observation are key considerations. Dry-formed sulphur has been proven (see Figures 1 and 2) to readily emit airborne particulate. This airborne suspension, generally of sulphur particles of 150 micrometres or less, eventually dissipates, harming the environment through acidifying pollution, and workers by irritating skin, eyes, throat and lungs. It can also readily ignite, causing explosions and/or fires at transfer points, conveyors and during ship-loading and unloading.

Breakage in transit

Research can provide guidance on potential solutions, although studies on volatile sulphur particulate are scarce. Our work in this area, shown in Figures 3 and 4, shows size profiles for the three principal types of formed sulphur. The first is 'as produced' and the second is 'as sampled at destination', in the hold of the arriving ship. Figure 3 shows tight to very compact profiles for all three processes. Virtually no material is apparent that is smaller than a 30 Tyler mesh screen, close to 0.5 mm, or 500 micrometres.

Figure 3, showing particle size distribution of the three samples taken from the hold of ships at their destination, demonstrates how the former large particles have degraded into smaller particles due to breakage during loading and movement of the cargo in transit. The most important comparisons for the purposes of this article are the changes in the amount passing through a sub-50 Tyler mesh screen – sized below 500 micrometres. This fraction of the samples goes from barely detectable when measured immediately following its production to easily identifiable in two cases, and a slight increase in the case of the GX product.

Figures 5 and 6 are yet another example of what happens in transit, using sieve analyses on two samples of formed sulphur taken from a single cargo of premium formed sulphur loaded in Ukraine. Obviously samples A and B look very different, but both come from loading the same sulphur into the same ship from the same storage area. Screening indicates each sample was materially different from the other. Each has very different proportions of sub-50 mesh/500 u m sulphur particles in the sample. The explanation for this could be due to many causes, having occurred during cleaning out of equipment, loading from a high elevation, crushing by reclaiming equipment, or loading from an area with old material in the stockpile. The fact is, nevertheless, that these are visibly different.

Combining two other samples and extensive screening provides preliminary indications that the material between less than 150 micrometres and greater than 75 micrometre particle size equals one half of one per cent of each sample. This is a very small percentage, but it means that a 30,000 tonne cargo would therefore contain 150 tonnes; 150,000 kg – a considerable amount – of such potentially airborne pollutant.

The electron microscope photograph in Figure 7 provides other insights into these particulates, underpinning our assumptions. Many particles can be seen to have a large flat surface area. This characteristic points in two directions. Firstly, surface tension will likely bind the 'flat' sides of two particles that come together. Surface tension is a powerful physical force, likely very difficult to overcome at this microscopic size. Thus, thoroughly moist sub-50 mesh sulphur particulate will likely be held together through the action of surface tension acting on flat particulate, preventing them from becoming individually airborne.

Secondly, spraying water on a layer of sub-50 mesh sulphur fines, as shown in Figure 8, leads to water 'beading'. No water is absorbed by and in the sulphur particulate. It is a hydrophobic material and repels moisture, preventing moisture from being inserted between particles. In this regard, sulphur dust is similar to most 'dust': the surface generally resists penetration of moisture, as seen in the right-hand photograph, with sulphur dust. As all children know, hot milk or water plus vigorous agitation is needed to prepare a good cup of hot cocoa! Without hot water and agitation, sulphur dust will not bind potentially volatile airborne particulates that are less than 150 micrometres into a non-volatile heavier particle.

Spraying dry sulphur travelling on a conveyor loading or taking it to storage therefore cannot achieve the needed effective mélange and create an effective bond between potentially volatile sulphur particulates. Given the kite-like flat shape seen in Figure 9, a strong surface tension bond is essential to mitigate airborne emissions. Active mixing, rather than spraying is the recommended solution.

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Conclusions

Our work in preparing for this year's IFA Technical and SHE Summit speech provided three conclusions:

1. Volatile sulphur dust experienced when handling formed sulphur is primarily composed of sub-150 micrometre particles. Many of these have a distinctly flat surface, making them apt to 'blow away' as if they were a piece of paper.

2. Moisture is an effective and economical means to control the dangers presented by airborne sub-150 micrometre sulphur particulate. Thorough dispersion of moisture throughout these particles will bind one to the other on the flat side, making them heavier and less prone to becoming airborne.

3. Thorough dispersion of moisture in the formed sulphur and accompanying particulate cannot be achieved through spraying alone. It must include immersion and agitation to be effective.

Sulphur is brittle and fractures easily, and sub-150 micrometre particles easily become airborne. Moisture prevents airborne particulates, so it is recommended that formed sulphur specifications should include a minimum moisture specification of 1.5-2%.

Postscript

The reader might ask: why be concerned about particulate volatility after formed sulphur is produced? After all, SUDIC Premium specifications are supposedly intended to guarantee a hard sulphur particle, resistant to breaking during handling. Without debating the level of Premium sulphur's crush resistance, the photographs in Figure 6 show why formed sulphur can never withstand all of the stresses present during transit. These examples represent only a portion of the 'abuse' experienced as sulphur is shipped and stockpiled.

Acknowledgements

This article is a synthesis of a speech prepared for the IFA Global Safety Summit, 23-26 March, 2015, Vancouver, Canada.

Figures 5-9

Figs. 5 & 6: Granular sulphur particulate: Sub-50 mesh, 300 micron (0.3mm), Odessa.

Fig. 7: Microscopic sulphur particulate.

Fig. 8: Water "beads" when sprayed on cocoa (left) and sulphur dust (right).

Fig. 9: Bulk handling of a friable product.

A twice yearly review contributed by
Alberta Sulphur Research Ltd

ASRL REVIEW

The Alberta Sulphur Research core research program

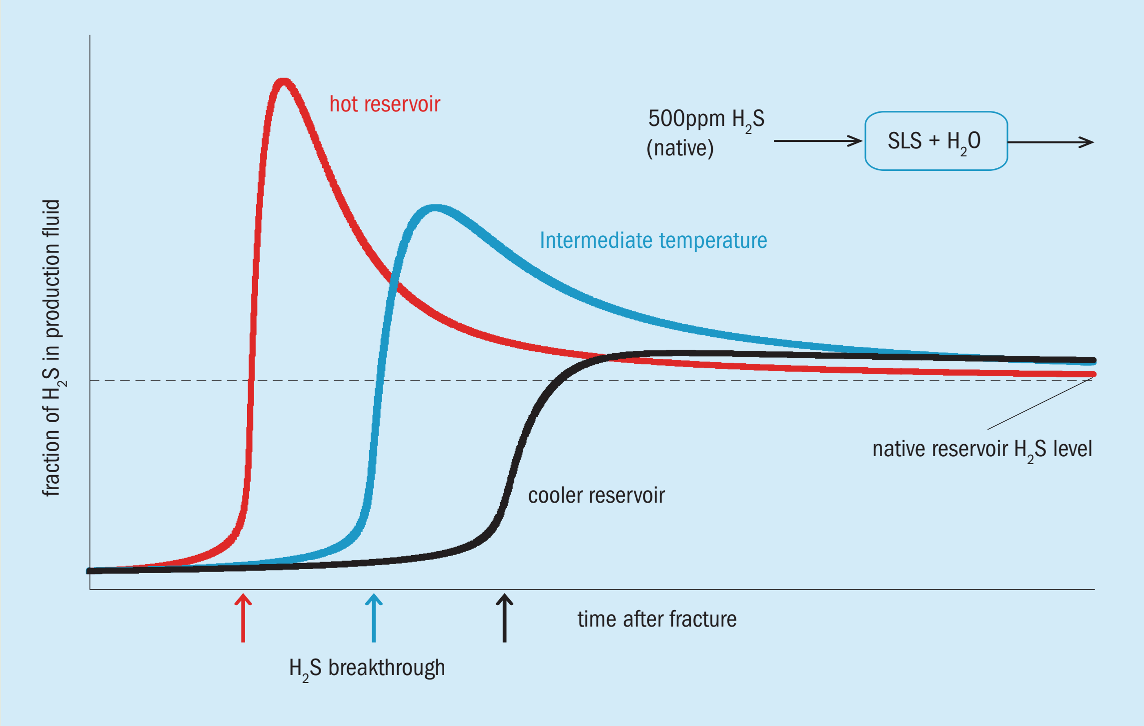
Peter D. Clark, Director of Research, ASRL and Professor Emeritus of Chemistry, University of Calgary, looks at the various research strands currently active within ASRL.

ASRL operates as a not-for-profit research organisation housed in laboratories at the University of Calgary. It was formed in 1964 to assist the sour gas industry then developing in Western Canada, providing information to solve short- and long-term problems that the industry was beginning to face. Today, after 51 years of operation, it still fulfills the same mandate, to produce and disseminate information in sulphur chemistry and technology. In addition to client confidential research, ASRL conducts a basic research program which is designed with the help of a member company advisory board, the Technical Advisory Committee. The following summary describes some of the research underway in the 2015-2016 programs:

Shale gas souring

Despite reticence to adopt new drilling and completion technology in some parts of the World, the USA and Canada is now enjoying some of the world's cheapest CH_4 supplies courtesy of horizontal drilling and fracturing of tight hydrocarbon bearing reservoirs. This copious supply of CH_4 is hastening the shuttering of inefficient coal-fired power plants and rejuvenating those North American petrochemical sectors which use the associated C2-C5 alkanes.

Fig 1: **A simplified mechanism for SDS degradation, scavenging H_2S and re-release of H_2S**



The complex mixture of water, minerals and chemicals used in 'fracking' technology, which includes the common biocide sodium lauryl sulphate (SLS), leads to some interesting and, at first glance, inexplicable changes in H_2S content during the initial phases of production (Figure 1). Sampling of the initial production has lead operators to conclude there is either no H_2S or only a small (50-2000 ppmv) amount present in the reservoir. Precise knowledge of the H_2S content is very important, as this factor determines what gas conditioning is required before addition to a pipeline distribution system. Work done under the guidance of Dr. Rob Marriott, ASRL-NSERC Professor of Industrial sulphur Chemistry, has shown that thermochemical sulphate reduction of the sulphate component of SLS is responsible for some or all of the H_2S, the amount initially observed being depend-

Fig 2: **Degradation of amines**

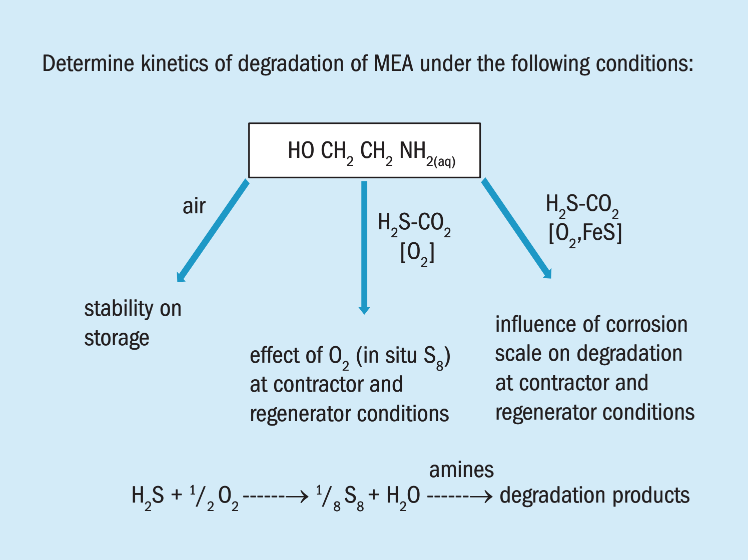


Fig 3: **The effect of methanol on the Claus furnace**

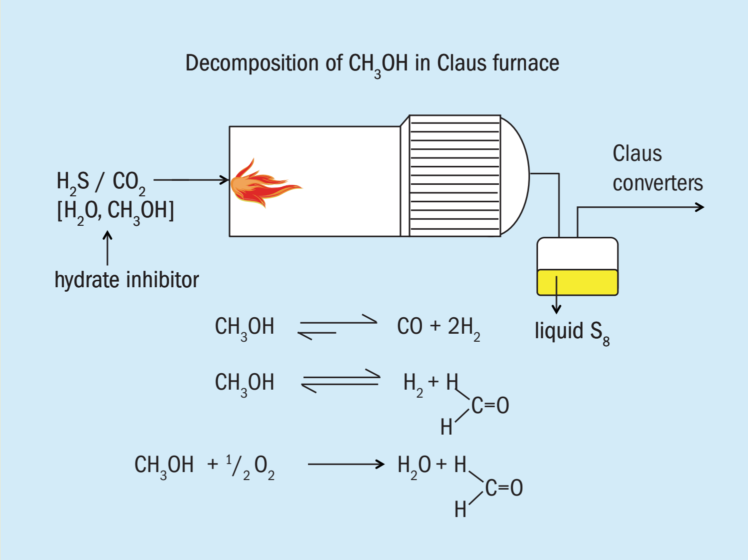
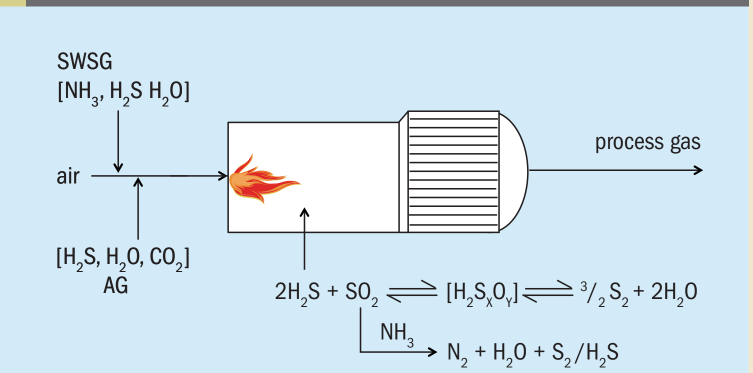
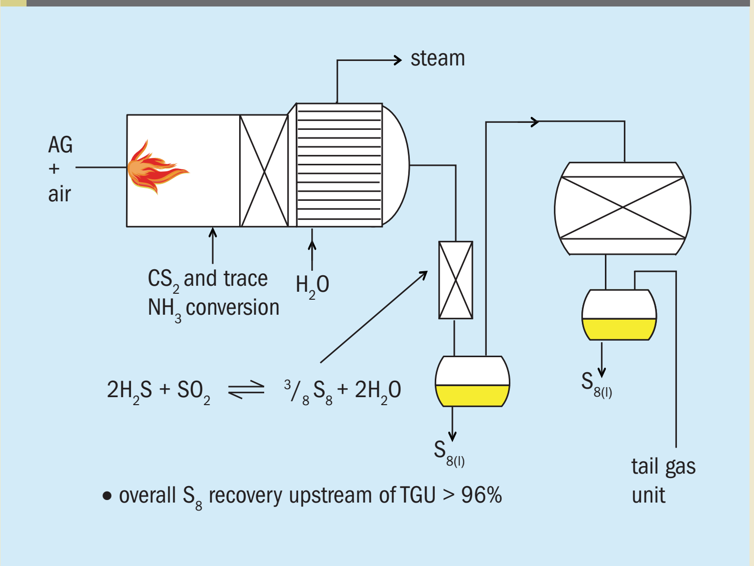


Fig 4: **NH$_3$ decomposition in the Claus furnace**



Project objectives:
- obtain kinectics for 2:1 and 4:1 H_2S/SO_2 outlet ratio at respective adiabatic temperatures [various t_{res}];
- compare to equivalent NH_3/SO_2 data set and obtain full feed data sets for kinetic analysis and determine efficacy of split flow designs.

Fig 5: **Simplification of the modified Claus furnace**



ent on the fracture fluid composition and the conditions within the reservoir. Since the amount of H_2S can change after the gas is brought on-stream, this research has shown that very careful sampling and the time at which the gas samples are taken is required before gas conditioning systems are designed and built.

Amine degradation

In general alkanolamines such as MEA, DEA and MDEA are chemically reactive species which are well known to degrade under amine plant conditions, especially if the temperature within the regenerator is not watched carefully. Although numerous pathways for amine degradation have been suggested and examined in the laboratory, many studies point to O_2 ingress into the amine plant as a major pathway of degradation, as decomposition products contain carboxylic acids or other O-containing functional groups. Practically, it is almost impossible to keep O_2 out of an amine plant, but it is not clear that O_2 is really responsible for amine degradation. Actually, this mechanism is quite unlikely as O_2 has very limited solubility in aqueous amine solvents and, so, should pass with the CH_4 from the contactor vessel.

Sulphur chemistry is more likely to be involved as O_2 reacts quickly with H_2S, forming elemental sulphur which, in the presence of H_2S, dissolves in the amine as an amine hydropolysulphide (Figure 2). These compounds are dissolved and, so, experience the high temperature conditions in the regenerator. Here, the sulphur-hydropolysulphide mixture oxidises susceptible C-H bonds leading to amine-sulphur compounds which hydrolyse to the familiar O-containing degradation products under the basic conditions in the contactor and regenerator. Unfortunately, because the sulphur and hydropolysulphide remain in solution through the contactor-regenerator loop, it is completely consumed over time, leading to amine degradation in an amount equivalent to the amount of O_2 that has reacted with H_2S. In addition to finding that O_2 reacts quite quickly with H_2S under contactor conditions, its conversion is also catalysed by corrosion scale or suspended FeS. Thus, filtration of particulates which catalyse H_2S oxidation and stopping O_2 ingress to the plant are the key aspects of minimising amine degradation.

Impurities in the modified Claus process

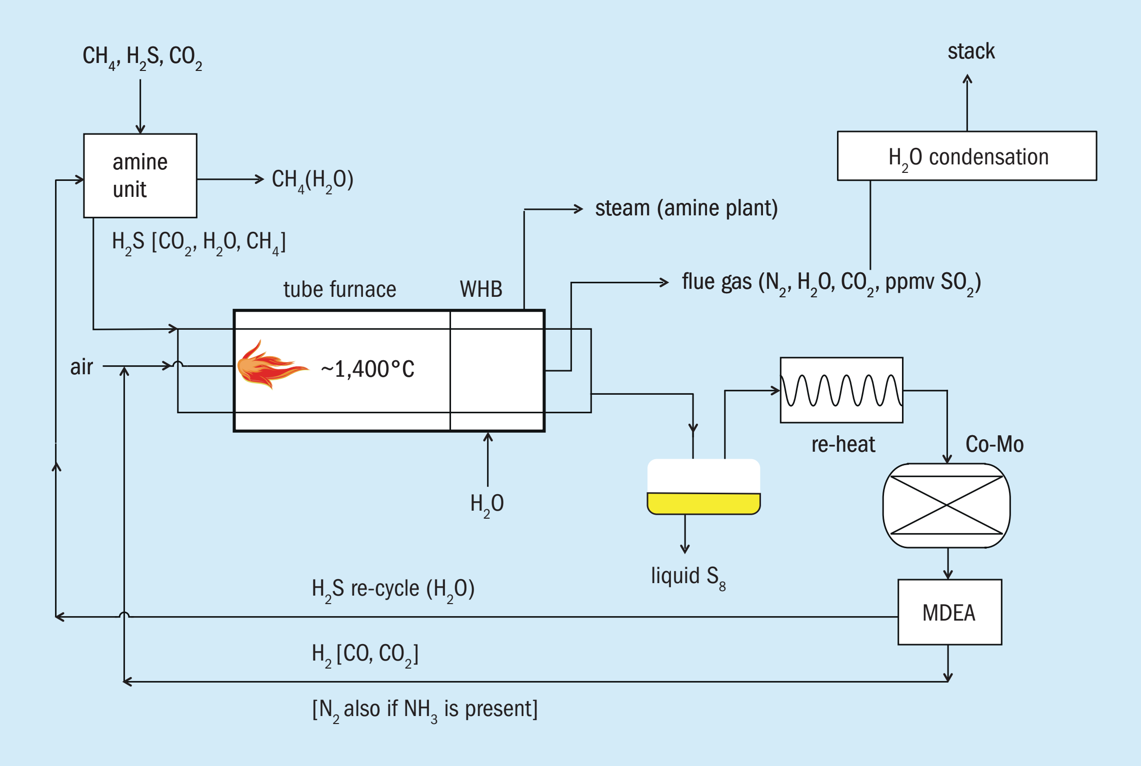
The Claus process would be much simpler if we did not have to deal with impurities in the acid gas feed to the main burner. Previously, we have looked at the effect of BTEX in Claus combustion, showing that complex pathways exist for conversion of these hydrocarbons, the most important of which are oxidation by sulphur and intermediates which are part of the Claus equilibrium. More recently, we have examined CH_3OH decomposition in the Claus furnace (Figure 3) showing that, as would be expected, it decomposes to CO and H_2 even at fairly moderate combustion temperatures (900°C). Only if CH_3OH is by-passed to a catalytic converter would problems be experienced as conversion to polysulphides and carsul would be expected at the catalyst surface.

NH_3 degradation to N_2 and H_2O in the partially oxidising conditions of the Claus furnace is another matter, as it may constitute as much as 35% of the material fed to the burner. Design engineers must deal with excessive temperatures for high NH_3 input and employ good mixing of SWSG and air streams to achieve high conversion to N_2. Work at ASRL has shown that creation of an oxidising zone in the SWSG conversion zone is important, as reaction

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84

between NH_3 and SO_2 is an important, if not the controlling mechanism for efficient destruction (Figure 4). Also, quenching of intermediate NH_2 radicals by H_2S and deactivation of activated NH_3 molecules complicates the overall kinetics of NH_3 destruction in a Claus furnace. Research currently underway in our laboratories has the objective of providing global kinetic data to aid furnace design and operation.

Fig 6: The dissociative sulphur recovery process



New directions in sulphur recovery

Despite its long history, further improvements to the modified Claus are being sought to improve reliability and lower capital and operating costs. One adaptation, described in part in a previous issue of this magazine (Sulphur 357, Mar-Apr 2015), aims to employ existing equipment and lessen the number of units used. Our latest research suggests placement of catalyst in front of the waste heat boiler tube sheet and in the piping downstream of the WHB will enable operation of a plant with only one formal catalytic converter and no re-heaters (Figure 5). The overall recovery in a plant would still be governed by the type of tail gas unit chosen for the system.

A more adventurous approach to sulphur recovery (Figure 6) moves away completely from the Claus process, instead employing H_2S dissociation as the heart of the process. However, instead of trying to use the hydrogen product of dissociation for external purposes, it becomes the fuel, in part, which drives the dissociation. This innovative approach can, in principle, allow >99.99% sulphur recovery with, perhaps the highest thermal efficiency of any system disclosed to date, because water is recovered as a liquid, so enabling heat of condensation to be harnessed. Although dissociative sulphur recovery is easy to conduct in the laboratory, design and construction of the WHB is a formidable challenge, as very rapid quenching of the process gas to <700°C is required to prevent the back reaction of products to H_2S.

Corrosion in tail gas lines

Tail gas lines after the last condenser and exiting the sulphur pit suffer both pitting and acid-type corrosion, although the tail gas composition differs significantly for these process gases with air as a major constituent for the pit off-gas. The reason for corrosion can, in most cases, be traced to deposition of liquid and solid sulphur, so improved heating of the lines is often applied to mitigate the corrosion. Our research has confirmed that this is the correct strategy in most cases, showing that not only is sulphur deposition a prerequisite to corrosion, but also that liquid water must be produced for rapid corrosion. Thus, un-insulated components in the line or simply failure of existing heating and insulation systems are the major reasons that promote line corrosion. One other mechanism may involve sulphuric acid which is produced upstream, and subsequent deposition of liquid acid in the lines, although it can be difficult to differentiate acid corrosion from that arising from water–sulphur deposition, as the FeS produced by the sulphur mechanism can be oxidized to acidic iron sulphates (Figure 7).

Sulphur pit fires

Some of the reasons why sulphur pits catch fire include ingress of FeS into air drafted systems and build up of static charge on sulphur droplets which, because of the electrically insulating properties of sulphur, discharge through the flammable air-sulphur mixture. Indeed, whether it involves piles of wood chips or even people, all cases of "spontaneous combustion" can be explained by static discharge through flammable

Fig 7: Corrosion in Claus tail gas – pit off-gas lines

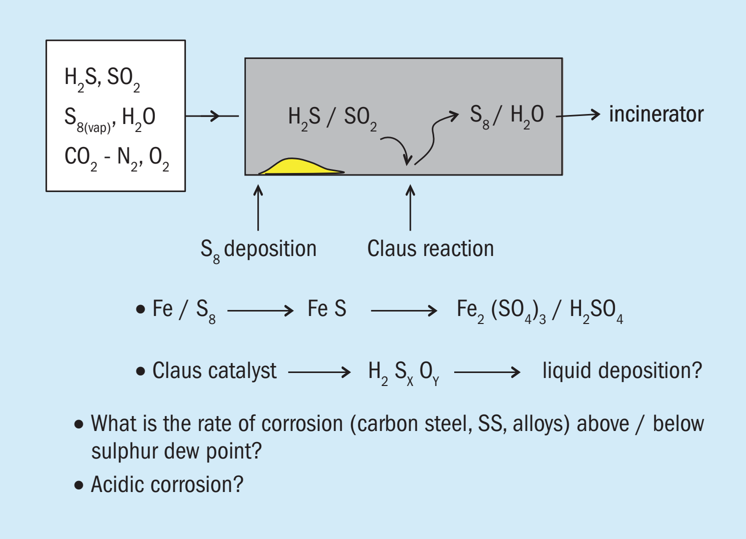
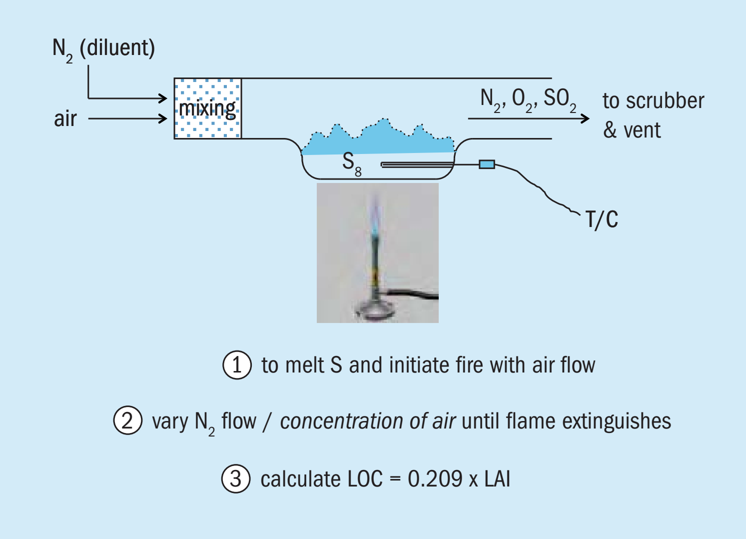


Fig 8: Limiting air concentration (LAI) for sulphur fires



Contents ISSUE 360 SULPHUR SEPTEMBER-OCTOBER 2015 BCInsight

material. For solid sulphur, friction or FeS are the most common reasons for ignition, but for liquid in run-down pits, the exact cause is difficult to pinpoint because the aftermath of a pit fire can be a bit of a mess.

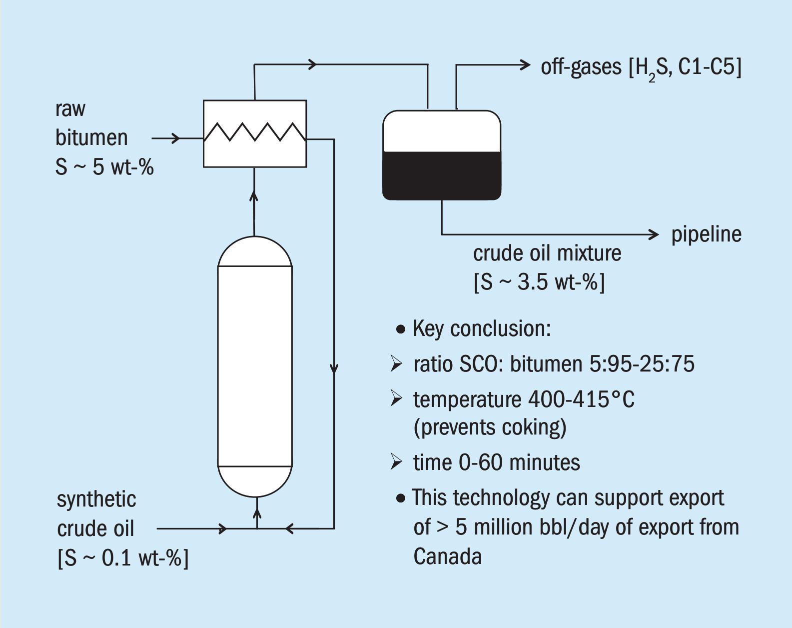
Normally, a pit fire is not discovered until it has been under way for some time, so the inner surface of the roof and walls may exceed the auto-ignition temperature of sulphur vapour in air (ca. 240°C) due to inadequate cooling. Thus, passing steam through the pit head space until no more SO_2 is detected, followed by re-introduction of air, may not be sufficient to stop re-ignition. If FeS is the cause, continued inflow into the pit will also re-ignite the fire when air is re-introduced. The main objective of the current ASRL project is to determine the air-steam composition which both extinguishes the fire and which would prevent re-ignition while the system is cooled to normal operating temperature (Figure 8).

Transportation of oil sands bitumen

At current oil prices, new projects for production of oil sands bitumen are "on hold", but the general sentiment is that the world will still need 5-10 million bbl/d of bitumen by 2030 in order to have any hope of meeting oil demand by that date. Indeed, bitumen is not only a valuable source of energy; the 1 trillion bbl of oil in place in Northern Alberta represents the world's largest known repository of sulphur, albeit in combined form. So, since ASRL focuses on long-term issues as well as current challenges, we have worked steadily towards a solution to transport of bitumen to facilitate offshore exports. In particular, we have focussed on removing the need for use of diluents for viscosity reduction.

The methodology for reduction of bitumen viscosity to pipeline specifications is simple, involving heating of bitumen with ca. 15 wt% synthetic crude oil (SCO) to 400°C (Figure 9). This process engenders H-transfer between H-rich SCO species and H-deficient bitumen asphaltenes and resins with permanent de-polymerisation of some primary and secondary high molecular weight structures. Further aspects of this chemistry, which parallels coal liquefaction technology, were described at Sulphur 2014 in Paris.

Fig 9: Primary upgrading of oil sands bitumen



The commercial advantage of this viscosity reduction approach is that removal of diluents from the transportation system allows a 30-50 % increase in the total pipeline capacity for bitumen transportation in North America. Moreover, rail transport of oil made by the ASRL process, now formally christened as the Alberta bitumen to crude oil (ABCO) process, is possible without heated rail cars or diluted product. Another key advantage of the ABCO process is that it produces a homogeneous product that does not separate and which can be tailored to produce a material which floats on water. This last point overcomes an environmental concern in the event that a spill of bitumen derived product occurs, since it is much easier to recover oil that floats on water.

At present, laboratory data confirm the validity of the ABCO process and a preliminary economic/engineering evaluation suggests that it is superior to existing technology. A pilot scale demonstration of the technology is planned to start in October 2015. Coupled with other technology now under development, the ABCO technology could drastically reduce emissions from oil sands developments and contribute to producing a secure supply of sulphur into the 21st Century. ■

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Sulphur recovery technology trends

Sulphur invited world leaders in the design, construction and licensing of sulphur recovery units and related sulphur management facilities to share information on the latest technological developments, current trends, challenges and concerns in the sulphur industry. Over the following pages they discuss, how to achieve world class performance, minimise operating costs, meet ultra-low SO_2 emissions standards, handle increasing amounts of ammonia in refinery feedstocks and improve sulphur safety.

AMEC FOSTER WHEELER

Two-stage sour water stripping – focus on H_2S stripper control

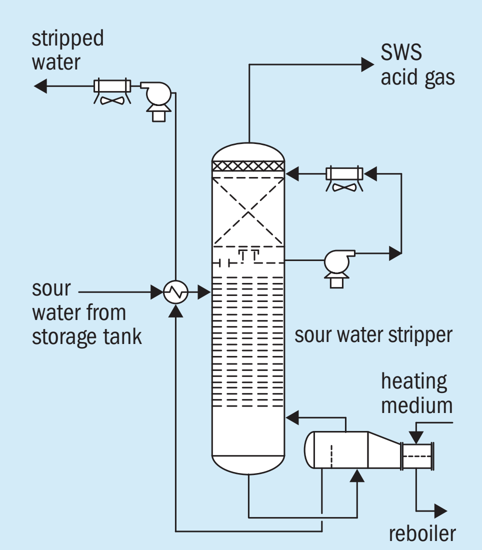
N Watts, Q Kotter, S Kafesjian

Coinciding with the current trends toward higher nitrogen-containing crude feed stocks and increased nitrogen conversion in hydroprocessing units, there is a growing interest by refiners for two-stage sour water stripping (SWS) technology as a means of coping with the consequent increasing amount of ammonia generated in the refinery process units. This ammonia is absorbed in the refinery sour water and must be treated in a SWS unit. Process simulation study results described herein show that the two-stage SWS process comes with interesting control challenges for process designers and plant operators.

The differences between a two-stage and a conventional one-stage SWS are shown in the simplified process flow diagrams in Figs 1 and 2. A conventional SWS consists of a single steam stripping tower that produces an overhead acid gas stream containing nearly all of the hydrogen sulphide and ammonia present in the raw sour water feed to the tower. This acid gas stream is typically sent to the sulphur recovery unit (SRU), where the ammonia is destroyed and the hydrogen sulphide is reacted to produce a recoverable stream of elemental sulphur.

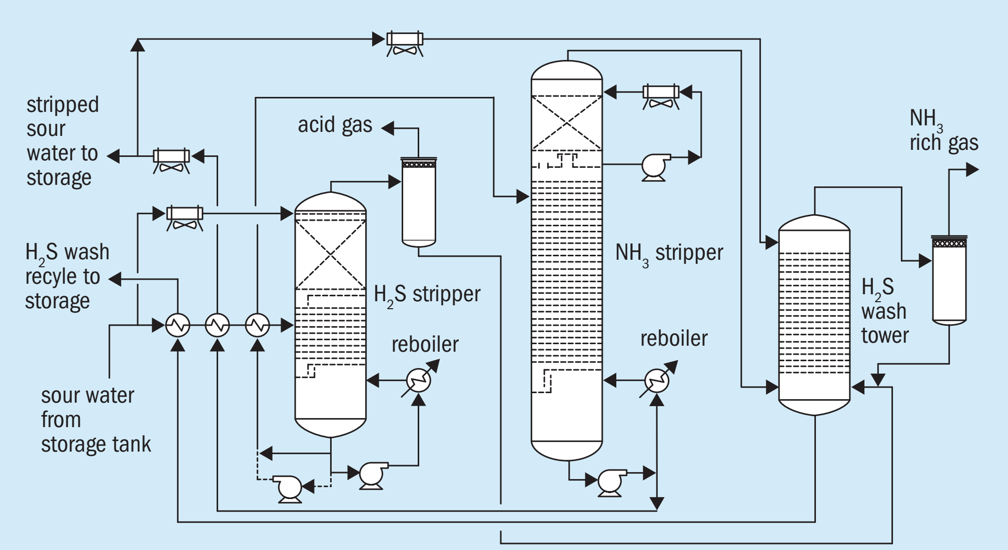
In a two-stage SWS, the raw sour water is steam stripped using two towers in series, with the stripping conditions controlled in the

Fig 1: **Conventional sour water stripper**



Source: Amec Foster Wheeler

Fig 2: **2-stage sour water stripper**



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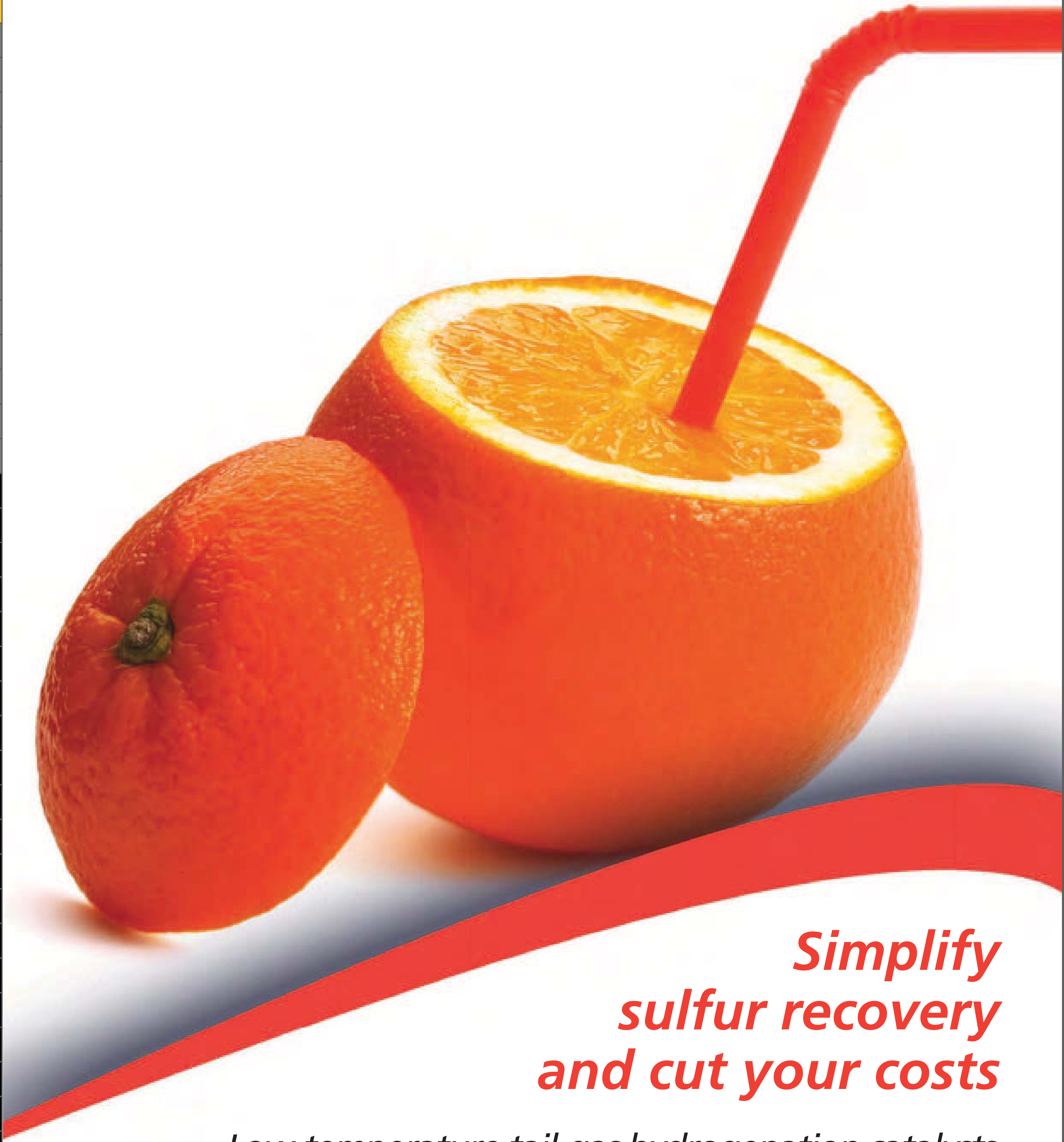

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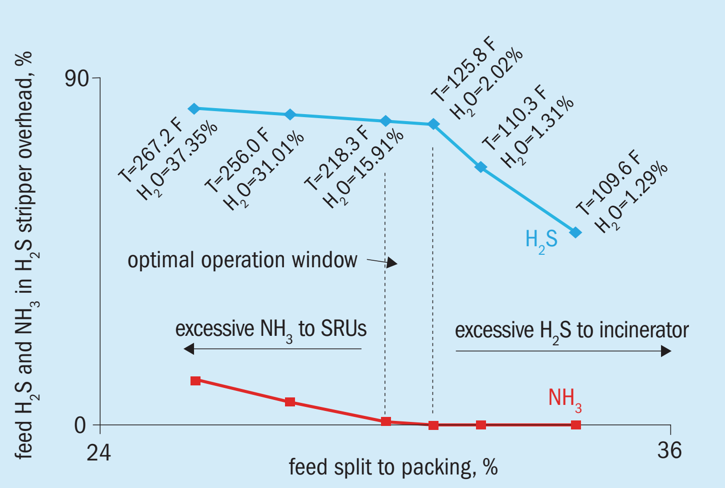
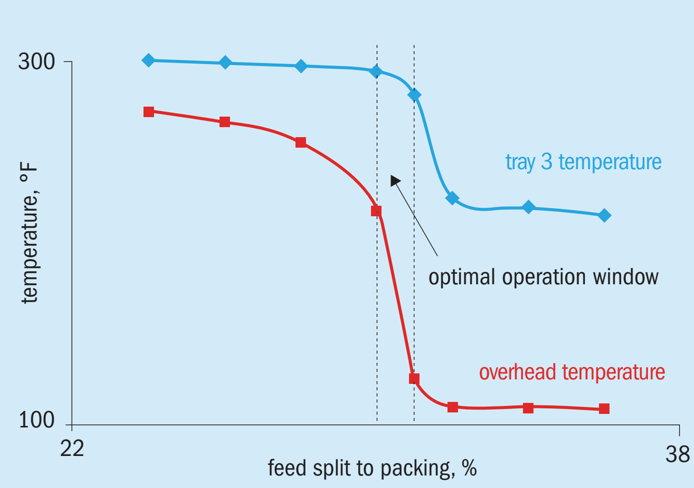
Fig 3: H_2S stripper overhead temperature and composition vs percentage of feed split to packing



Source: Amec Foster Wheeler

Fig 4: H_2S stripper overhead and tray 3 temperatures vs percentage of feed to packing



Source: Amec Foster Wheeler

first tower (H_2S stripper) to strip only hydrogen sulphide. The H_2S stripper overhead acid gas is sent to the SRU as usual. The second tower (NH_3 stripper) operates identically to a conventional one-stage stripper, stripping nearly all of the ammonia plus any residual hydrogen sulphide. The overhead from the NH_3 stripper is sent to a third tower, where the acid gas is washed with stripped water to reabsorb the hydrogen sulphide present in the acid gas. Hydrogen sulphide can be absorbed in the wash tower water due to the ammonia that is also absorbed. The washed (H_2S-free) ammonia gas can then be destroyed in a special ammonia incinerator or recovered as a product (aqueous or anhydrous ammonia). Removing the ammonia from the SRU feed increases the SRU capacity for hydrogen sulphide rich acid gas.

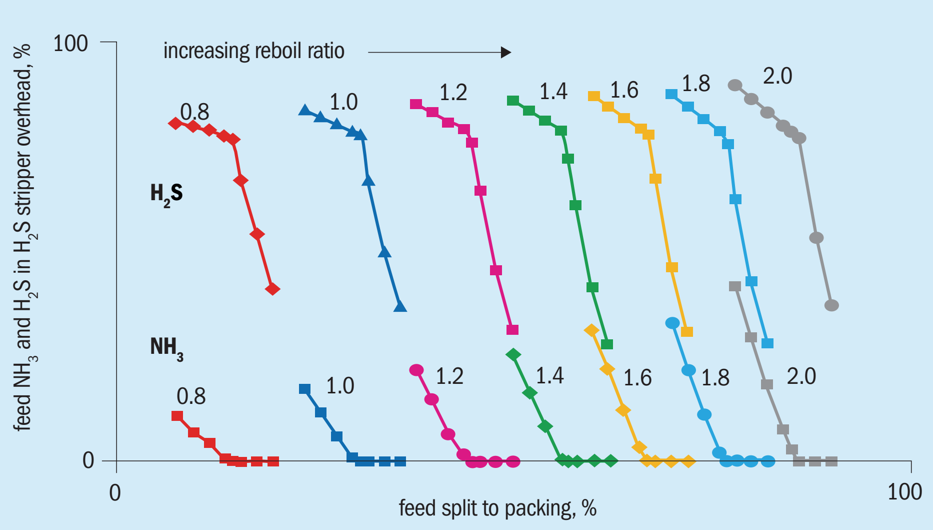
Each mole of ammonia removed from the SRU feed can be replaced with 1.5 moles of hydrogen sulphide, which means that three tonnes of hydrogen sulphide can be processed for each tonne of ammonia removed. As an added benefit, the well-documented SRU operational risks associated with burning ammonia are avoided.

A critical aspect of operating a two-stage SWS is controlling the H_2S stripper to maximise the stripping of hydrogen sulphide without also stripping excessive ammonia. Severe process consequences can result from either under-stripping or over-stripping in this tower. Under-stripping results in the carryover of hydrogen sulphide in the sour water feed to the NH_3 stripper, which then may result either in an H_2S breakthrough in the wash tower overhead (and the incinerator or ammonia product), or an increased wash tower bottoms recycle stream that consumes system capacity for fresh sour water feed. On the other hand, over-stripping results in NH_3 breaking through in the H_2S stripper overhead, diluting the acid gas and defeating the purpose of the two-stage stripping process. A small amount of over-stripping is preferable to under-stripping, as it ensures that the hydrogen sulphide stripping is maximised.

Stripping intensity in the H_2S stripper is determined by the temperature at the top of the tower. The optimum temperature varies depending on the sour water feed composition, and can best be determined by process simulation. Achieving the optimum temperature requires managing the reboiler duty and cooling sink at the top of the tower in concert with the sour water feed enthalpy. A minimum reboiling duty is required to keep the tower operable; little benefit is gained from operating with elevated reboiling duty. The cooling sink is achieved by adjusting the sour water feed split between the precooled feed to the packed section and the preheated feed to the stripping section of the tower.

An interesting process control challenge in the two-stage SWS configuration is illustrated in characteristic Figs 3-5. The axis scales have been removed from the figures for brevity and to highlight trends. Figure 3 shows that, for a given reboil ratio (defined as reboiler steam rate divided by feed rate) the H_2S stripper overhead composition is sensitive to the sour water feed split to the packed section of the tower. Also, there is a noticeable inflection point

Fig 5: H_2S stripper overhead composition vs percentage split to packing for various reboiling ratios



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in the relationship between the hydrogen sulphide and ammonia content in the overhead and the feed split. The optimum operating point is in a narrow feed split range at or slightly above the inflection point in the hydrogen sulphide stripping curve.

Figure 4 shows that, within the feed split range for optimum stripping in Fig. 3, there is coincidentally a strong sensitivity of the tower overhead temperature to feed split. The sensitivity is so great, in fact, that overhead temperature is likely not a good choice of control variable. However, the temperature on the tray above the feed tray is less sensitive to the feed split and likely a better choice for controlling the tower operation than the overhead temperature.

Given the difficulty of controlling the overhead or tray temperature by adjusting the feed split, other options for controlling the stripping intensity were considered. One option is shown in Fig. 5, which shows a series of curves analogous to those on Fig 3, but for a range of reboiling ratios. Each reboiling ratio has a specific feed split that achieves the optimum stripping intensity. Extending vertical lines from the inflection points on the H_2S curves down to the horizontal axis, a series of feed split points is generated that represents a curve for controlling the feed split as a function of the reboiling ratio. For a given sour water feed composition, the optimum tower temperature is the same at all of the reboiling ratios, and the temperature is used as a check to ensure that the stripping intensity is in the correct range.

Several H_2S stripper control modes using combinations of sour water feed split, stripper overhead or tray temperature, and reboiling ratio may be useful. It is recommended that control logic be provided to accommodate at least these:

Tray temperature control based on feed split, at a specified reboiling ratio – this is the most direct means for controlling the stripping intensity, but requires a stable (flow rate and composition) sour water feed and steady-state operating conditions.

Feed split control based on reboiling ratio – this mode avoids the requirement of responding to rapid and large swings in the tower temperatures.

Feed split control based on reboiling ratio with tray temperature high and low limits – this mode may be the most reliable.

The optimum H_2S stripper tower temperatures change along with changes in the composition of the sour water feed. In any control mode, therefore, the optimum tower temperatures must be determined by sampling and simulation.

Complex dependencies and non-linear responses exist among the process variables in the two-stage SWS process. If not studied and accounted for during the design phase, the complexities create a challenge in achieving and maintaining the optimum operating conditions in the H_2S stripper, and are indicative of the need for a high level of training and operating experience. The types of non-linearities discussed in this article also underscore the necessity of the often-overlooked design step of performing process simulations over a range of critical operating variables to understand how shifts in operating conditions affect the overall operation of a unit.

The complexities are also indicative of the importance of providing a steady and stable sour water feed to permit achieving and maintaining an optimized operation. Large sour water storage capacity is critical; at least 3-5 days of storage time is strongly recommended.

BLACK & VEATCH

SRU overpressure due to tube rupture

S Polise, A Mosher and D Ogg

Protection of sulphur recovery units (SRUs) from overpressure requires consideration for the unique nature of the potential causes. Two common causes of potential SRU overpressure have been determined to be deflagration within the fired equipment and SRU waste heat exchanger (WHE) tube leaks/rupture (failure). Newer plant designs typically use a reaction furnace design pressure of 50 to 80 psig to account for the potential deflagration pressures. This pressure range is based on NFPA 69 guidelines for pressure containment allowing deformation but not rupture. In contrast to deflagration, overpressure by SRU WHE tube rupture is not uniformly evaluated or acknowledged within the industry.

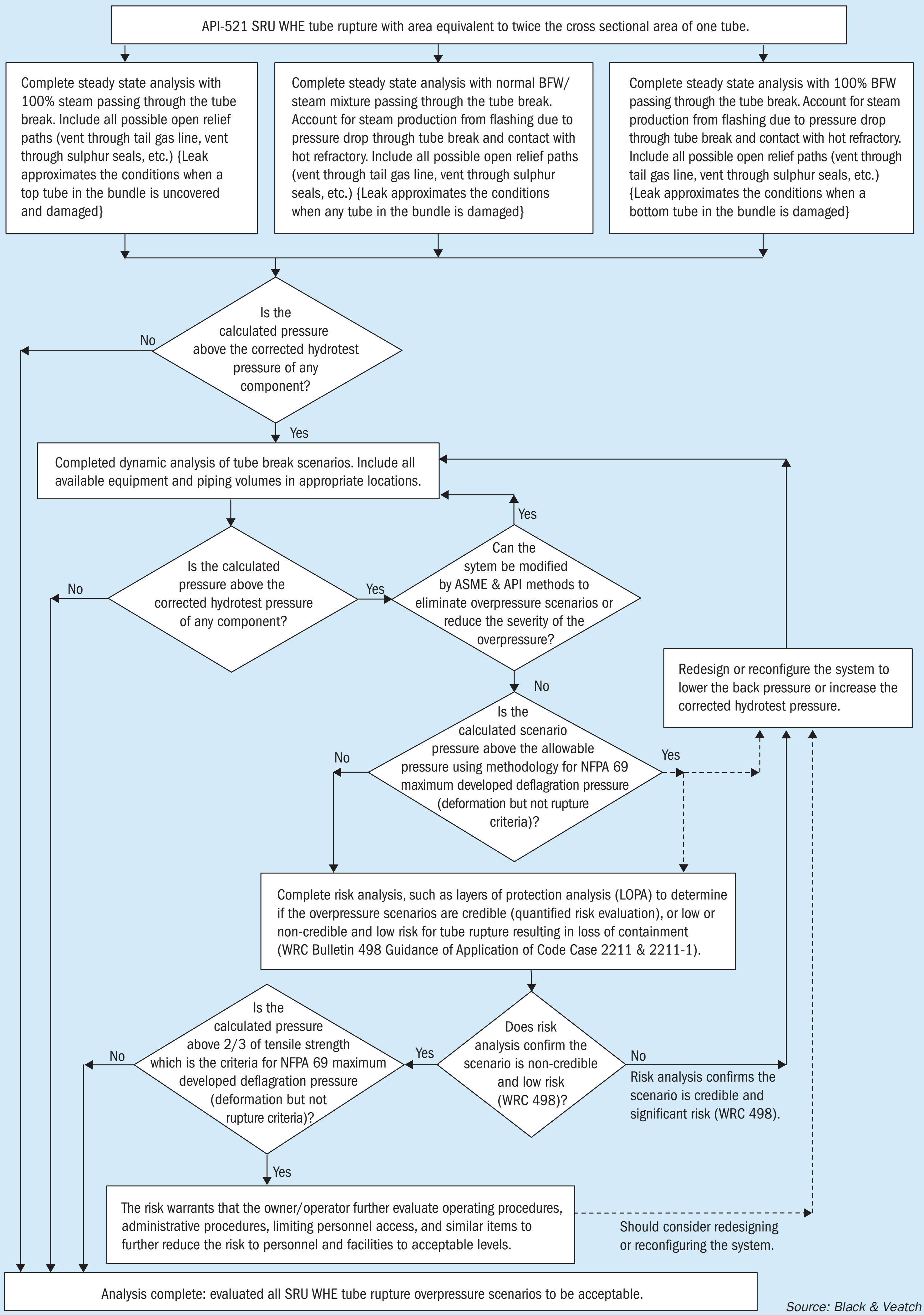
The traditional methods for overpressure protection (relief valves and rupture disks) typically will not work in an SRU for various reasons largely associated with lack of safety and reliability tied both to the device and to the venting destination.

Because of the unique conditions within the SRU, the overpressure protection scheme has come down to ensuring that there is always an open path from the SRU WHE to the Incinerator by making sure that one of the tail gas valves is always open (an open valve to force all gases through the tail gas treatment unit (TGTU) or an open bypass valve to force all gases to bypass the TGTU). Traditional sulphur seals, as well as the newly developed S_xSeal™ 2000 concept from Controls Southeast, Inc. (CSI), by their very nature will also act to relieve some of the built-up back pressure during an overpressure situation, although the relieving assistance they provide will vary.

Over the years, Black & Veatch and others have completed steady-state built-up back-pressure analyses based on different assumed combined hole sizes in the SRU WHE tubes. At the 2014 Brimstone Sulfur Symposium in Vail, Colorado, Mosher and Ogg of Black & Veatch utilised dynamic simulation analysis for select case studies to illustrate the impact that a clean double-ended tube break in an SRU WHE will have on the built-up back pressure. While it is a widely held belief that a clean double-ended break of a single tube in an SRU WHE is a conservative approach, it remains an appropriate starting point for establishing the proper industry benchmark for this analysis and also for complying with current American Petroleum Institute (API) standards for relief scenarios.

Three double-ended break scenarios were evaluated comparing built-up steady-state versus dynamic back pressures for a sample SRU: a double-ended clean break of a single tube (i.e., only steam passing through the broken tube), steam and boiler feedwater (BFW) passing through the broken tube and only BFW passing through the broken tube. In each case, the unit considered a robust WHE design criteria, which is described in detail. A robust WHE design primarily includes two-pass exchangers with a

Fig 1: **Sequence of analysis flowchart**



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separate steam drum and design pressures on the process side commensurate with the deflagration containment standards mentioned above (50 to 80 psig).

Each scenario was studied as it applied to three different sizes of SRUs: a large SRU (approximately 640 long t/d]), a medium SRU (approximately 155 long t/d) and a small SRU (approximately 78 long t/d). The back-pressure results that use relieving rates associated with traditional belowground sulphur seals were also compared with back pressures calculated using CSI's S_xSeal™ 2000 sealing technology.

The exact results from the individual cases examined in this Black & Veatch analysis are extensive and beyond a tabular summary, but the following fundamental conclusions were established:

Because steam pressures, WHE design, downstream equipment configuration, unit capacity (equipment sizes), design pressure, sulphur seal technology and other key parameters may vary, the results of this analysis cannot be applied universally. In each case, the plant must be individually evaluated to account for unique circumstances.

If steady-state analysis of a tube rupture shows that the built-up back pressure in the equipment exceeds the equipment hydrotest pressure, then dynamic simulation should be used before any money is spent on design or equipment modifications. For the cases studied, all of the dynamic analyses showed pressure build-ups of less than the hydrotest pressure.

An important factor to consider in the dynamic analysis is the reverse flow of steam from the high-pressure (HP) steam header through the non-return check valve on the HP steam drum outlet line back into the process system under evaluation. For the cases considering no such backflow and a finite steam volume (i.e., two non-similar check valves routinely inspected and maintained), sulphur seal technology did not have much impact on the maximum built-up back pressure that was achieved using the dynamic simulation. The reverse flow has no impact on steady-state analysis.

The dynamic analysis provides significantly lower calculated built-up back pressure within the SRU than the steady-state calculations because of the volume available within the unit to absorb or dampen the pressure spike caused by the increased flow for finite steam volume systems (i.e., no reverse HP steam flow from the header). For infinite steam volume systems considering full reverse flow of HP steam from the header, the dynamic back pressure calculated nominally approaches the steady-state results.

The amount of time required to complete the necessary dynamic analysis of a tube leak/rupture is significant; it is estimated that doing a single SRU analysis dynamic model could take anywhere from 80 to 300 hours, depending on complexity.

The results of dynamic simulations should be scrutinised carefully to make sure that the end results seem reasonable and can be justified on the basis of other comparisons; there is considerable complexity to the inputs of a dynamic model.

API Standard 521, *Pressure-relieving and Depressuring Systems* (current edition: 2014), is being revised to include information regarding SRU reaction furnace waste heat boiler (WHB) tube-rupture-developed process side overpressure and other updates. In the end, each owner/operator must establish its own process for evaluating overpressure from an SRU WHB tube rupture scenario. No concise guideline on how to approach this analysis existed in the public domain until this year. At the 2015 Brimstone Vail Sulfur Symposium, for the first time to date, a published uniform guideline on how to complete this analysis for an SRU WHE was presented by Martens and Mosher.

The suggested sequence of analysis flow chart is depicted in Fig. 1. The flow chart is based on the author's experience in completing the analysis for SRU reaction furnace WHB tube-rupture-developed process side overpressure. The 2015 Brimstone paper also provides five separate examples of how the flow chart could be applied. ■

FLUOR ENERGY & CHEMICALS

Fluor/GAA's D'GAASS liquid sulphur degassing technology

M Chou, T Flood, T Chow and S Fenderson

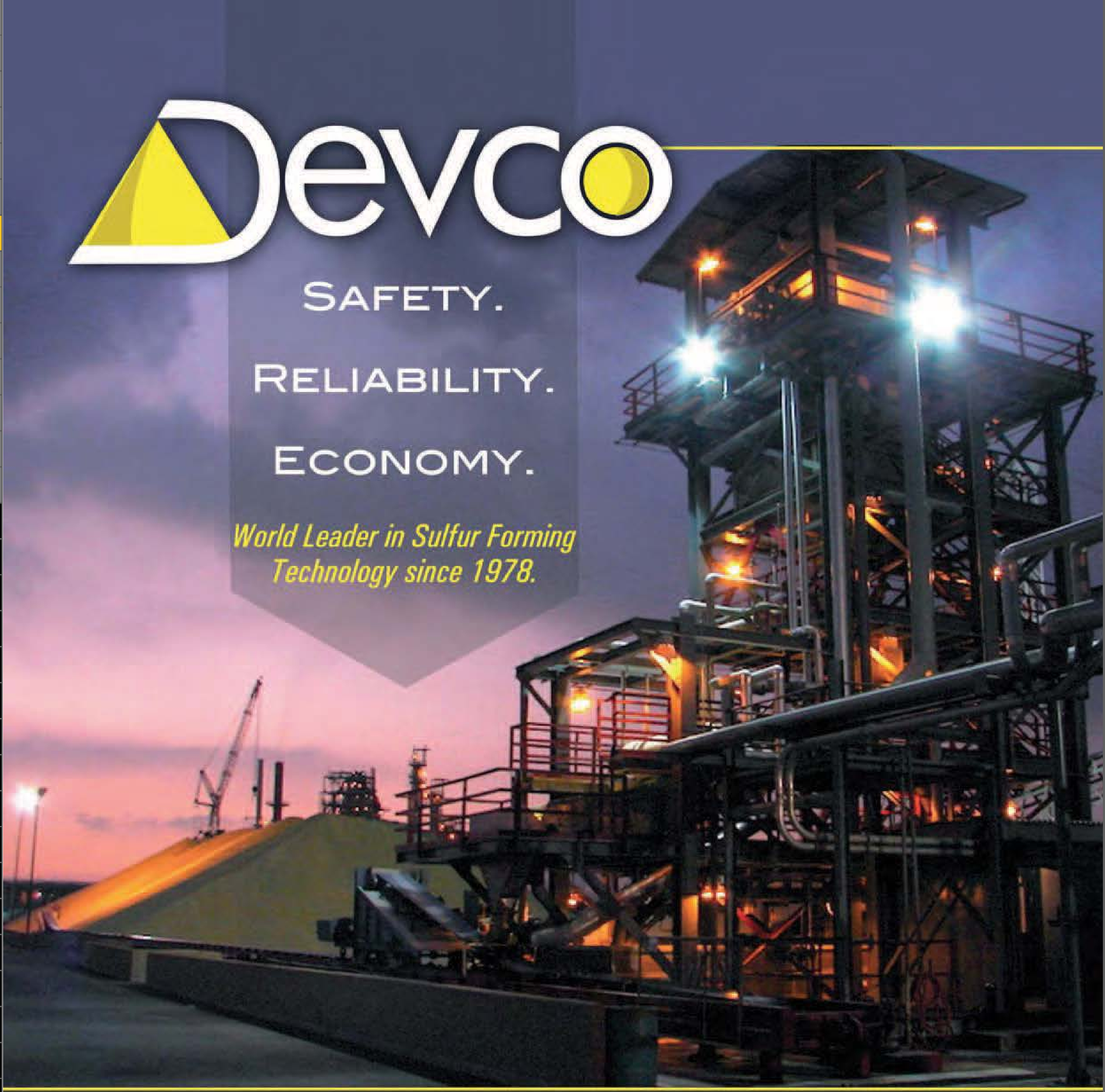
Degassing the liquid sulphur produced from a Claus sulphur recovery unit is necessary to both limit emissions and enhance safety. The unique features and process enhancements of Fluor/GAA's D'GAASS sulphur degasification process establish it as a leading technology in achieving this goal.

Liquid sulphur produced from a Claus SRU typically contains 200 to 350 ppmw H_2S, partially dissolved and partly present in the form of polysulphides (H_2S_x). If liquid sulphur is not degassed, H_2S will be released during storage, loading, and transport, potentially exposing personnel to toxic gases, or even creating an explosive mixture of H_2S in air. Undegassed sulphur can also impact the neighbourhood by creating a noxious odour problem when H_2S is released from the sulphur. In addition, solidification of undegassed sulphur is problematic, forming a more corrosive and friable solid product and frequently emitting noxious odors as H_2S is released from the solid sulphur.

D'GAASS process description

The Fluor/GAA D'GAASS sulphur degasification process accomplishes the removal of H_2S and polysulphides (H_2S_x) from liquid sulphur in a separate, pressurized vertical vessel outside of the sulphur pit. The vessel can be located at any convenient location between the rundown pit and storage, and the relatively small footprint of the D'GAASS equipment allows an easy fit for both existing and new plants. For existing SRUs, the sulphur rundown pit/tank acts as the degassing unit feed tank. No changes other than upgrading the sulphur pumps to higher head feed pumps are required for an existing sulphur pit. For new installations, installing a small sulphur rundown collection vessel or a small concrete pit for collection of the sulphur produced in the SRU is recommended. The collection pit only needs to be large enough to permit installation of sulphur feed pumps and required nozzles and to provide a few hours of surge capacity.

Undegassed sulphur and dry process air are the only feeds to the contactor; chemical catalysts are not used. Undegassed sulphur is pumped from the sulphur rundown collection pit/tank to the vessel normally at the unit's sulphur production rate. Since the Claus process produces sulphur at a



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temperature typically above the optimum for degassing, the feed stream is normally cooled by indirect heat exchange with boiler feed water or a closed-loop generation of low-pressure steam to increase degassing efficiency. In the vessel, it is intimately, counter-currently contacted with pressurized process air across efficient vapour-liquid contacting internals. The D'GAASS Process removes H_2S and H_2S_x through two mechanisms, oxidising most of the H_2S and H_2S_x to sulphur, and stripping the balance of the H_2S from the sulphur. Process air provides oxygen for reaction, agitation of the sulphur, and stripping of H_2S and is used as the stripping gas because of its advantage in the liquid phase direct oxidation of some of the H_2S/H_2S_x to sulphur. The process air requirement of the D'GAASS unit can often be met from the plant's instrument or plant air system.

The D'GAASS contactor operates at elevated pressure to increase the partial pressure of oxygen and concentration of dissolved oxygen in the liquid sulphur. This allows faster oxidation of H_2S and H_2S_x to sulphur and SO_2, which can react with H_2S via the Claus reaction to form additional sulphur. The overhead vapour stream from the contactor is pressurised air with ppm concentrations of H_2S, SO_2, and sulphur vapour and can be sent directly to the incinerator. Alternatively, the elevated D'GAASS operating pressure allows sending of the overhead vapour stream to the SRU thermal stage, tail gas unit burner, or selective oxidation reactor. In addition, degassed sulphur is sent to sulphur storage usually without additional pumping.

At the recommended operating conditions, the H_2S content is reduced to less than 10 ppmw $H_2S + H_2S_x$ (as H_2S) maximum in the degassed sulphur, as determined by FTIR analysis. This is accomplished during a required residence time of minutes, as opposed to the hours or days required by other commercial processes. The low residence time allows the sulphur collection pit/vessel to be operated at its lowest practical level, minimising H_2S release upstream of the D'GAASS unit to the Incinerator or the atmosphere.

In addition, the residence time required allows the use of a smaller contactor which results in lower capital costs and smaller plot requirements. An uncomplicated installation process – there is no need for sulphur pit/tank drainage to make the retrofits required – avoids long shutdown time for the unit and high installation costs. Maintenance and operating requirements are also lower. Since the D'GAASS contactor operates with fixed internals, very low fluid velocities, and few control valves, maintenance requirements are lower compared to other processes. The only rotating equipment items are the sulphur pumps and process air compressor (if required). Utility usages are power for the sulphur feed pump and air compression (if required), steam for heat tracing, and instrument air. As mentioned previously, there is no continuous chemical injection cost. Thus, the D'GAASS process allows for simple, reliable operation with low maintenance and operation requirements.

PHOTOS: FLUOR/GAA

Standalone D'GAASS unit.

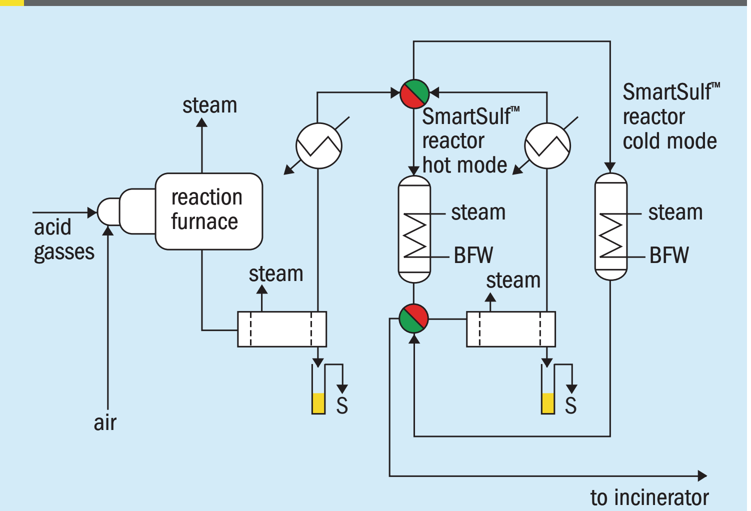
Though a smaller footprint and uncomplicated equipment is required, Fluor/GAA D'GAASS sulphur degasification process is not limited to smaller units and can be applied to a wide capacity range. Recent installed units range from the 8.5 t/d degassing unit for Neimeng Guotai in Inner Mongolia to the 4 x 2,500 t/d units for Al Hosn's Shah Gas Development project and the 2 x 2,600 t/d for the TengizChevrOil gas complex. Since the first installation in 1996, Fluor/GAA D'GAASS sulphur degasification process has been proven in over 100 licensed units with a total capacity of over 70,000 t/d.

PROSERNAT

New applications for SmartSulf™ technology

At the end of 2014 Prosernat acquired the German company ITS Reaktortechnik GmbH, owner of the SmartSulf™ sulphur recovery technology. Since then two new SmartSulf™ licenses have been granted by Prosernat for refinery projects in Russia, a 15 t/d unit for Transbunker Vanino and a 115 t/d unit for JSOC Bashneft. The SmartSulf™ process is a breakthrough sulphur recovery technology based on the use of internally cooled catalytic reactors (see Fig. 1). In the SmartSulf™ process the first catalytic reactor is operated at temperatures above the sulphur dew point where the second catalytic stage is operated under sub-dew point conditions. Once the second catalytic reactor is loaded with liquid sulphur it is automatically switched through switching valves, to first reactor, and the accumulated sulphur is then vaporised and recovered in the sulphur condenser. This mode of operation allows sulphur recoveries of 99.5+% in a two-stage unit without the need for downstream tail gas treatment. High performances have been demonstrated in several industrial units with more than 20 years of excellent operational feedback.

Fig 1: **SmartSulf™ process scheme**



Source: Prosernat

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RAMESHNI & ASSOCIATES TECHNOLOGY & ENGINEERING (RATE)

SO_2 stack emission of 10 ppmv has become a reality

M Rameshni

As environmental regulations have become more stringent around the world, investors are pushing for stack emissions of 10 ppmv SO_2 or zero emissions. In fact, the majority of requests for proposals received by RATE require stack emissions of no more than 10 ppmv of SO_2. In the US, China, India, Venezuela, Kuwait, and parts of Asia especially those dealing with the World Bank for investment and loan applications, compliance with 10 ppmv of SO_2 in the stack is mandatory.

In the US, RATE designed its first sulphur recovery and tail gas treating unit to meet 10 ppmv of SO_2 several years ago and it has now been in operation for three years.

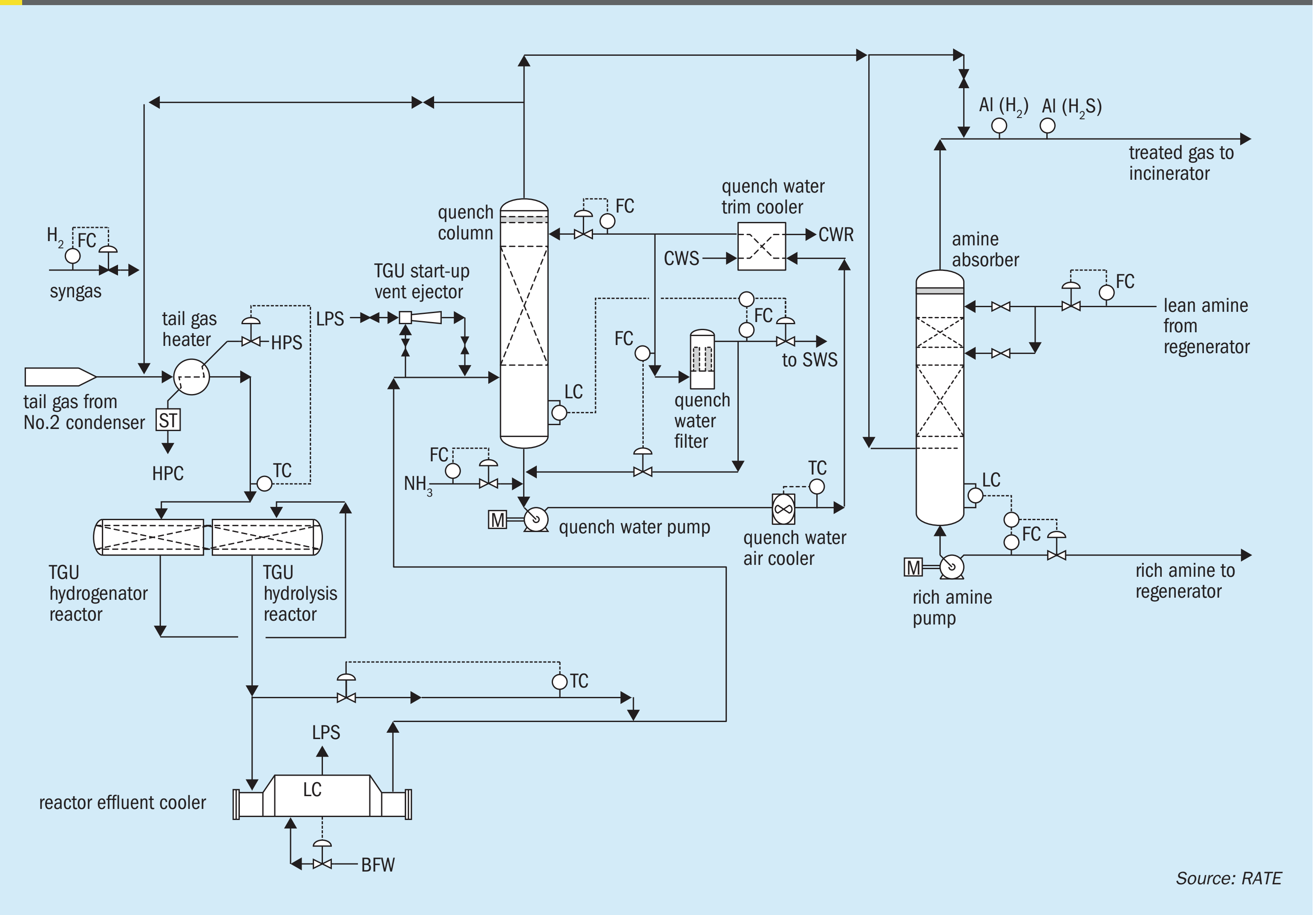
In addition, RATE recently licensed a new sulphur plant in China for a gasification application where the key major selling point was meeting 10 ppmv of SO_2 in the stack.

New SRU and TGU process technology has been patented for higher recovery in the SRU followed by a tail gas treating process to meet less than 10 ppmv of SO_2. The technology has been implemented for a Chinese customer for a gasification application. The patented process is a new innovation in sulphur recovery and tail gas treating; however, the focus of this article is limited to a discussion of the tail gas treating section only which promotes 10 ppmv of SO_2.

It is known that the feed composition to the sulphur recovery unit has an impact on the overall sulphur recovery. Rich acid gas contains high H_2S and low CO_2 and produces lower levels of byproducts such as COS and CS_2 in the Claus reaction, while lean acid gas contains low H_2S and high CO_2 and produces higher levels of byproducts. In gasification applications, the feed composition contains low H_2S and is rich in CO_2, resulting in higher levels of COS and CS_2 from the reaction furnace.

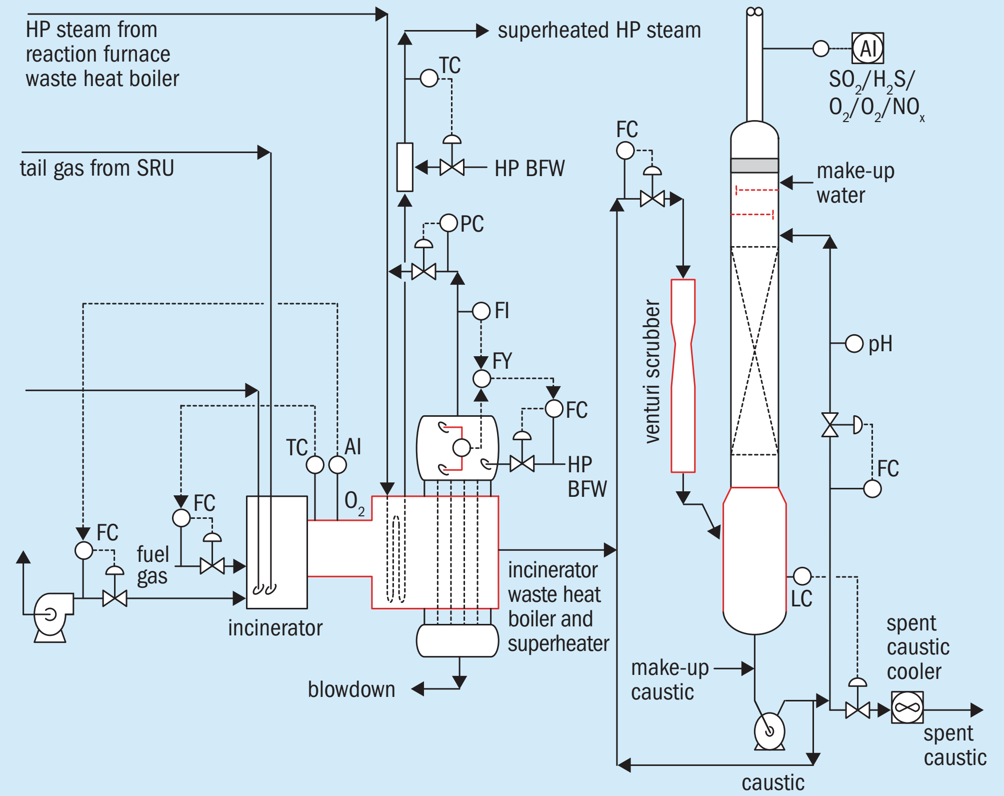
The tail gas feed from the proprietary sulphur recovery design of the gasification project flows to the tail gas unit, where all the sulphur compounds are converted to H_2S and recycled to the reaction furnace. The pit vent is also routed to the reaction furnace. The tail gas unit consists of the hydrogenation reactor with low temperature hydrogenation catalyst. As part of the new invention an additional reactor is added, the so-called hydrolysis reactor. Both reactors are in one shell to hydrolyse the remaining of COS and CS_2 and any sulphur compounds. Based on actual operating data the amount of COS and CS_2 is approximately 30 ppmv after

Fig 1: **RATE tail gas treating process for zero emissions**



Source: RATE

Fig 2: **Thermal incineration with caustic scrubbing**



Source: RATE

the hydrogenation reactor even though the simulation cannot predict that. As part of the new patent pending process the remaining COS and CS_2 is hydrolysed in the hydrolysis reactor. The gas is cooled and flows to the quench system where additional water is condensed then it is processed in the tail gas amine unit using a formulated selective solvent like HS-103 from Dow, or similar solvent from INEOS, Huntsman or Flexsorb SE plus from ExxonMobil. The stream to the incinerator is therefore only absorber overhead containing less than 10 ppmv of H_2S. As a result, a stack emission of less than 10 ppmv of SO_2 can be achieved on a regular basis without significant additional cost – addition of one reactor and possible change of solvent from generic to formulated solvent only. The following diagram represents the tail gas section of the patented process.

RATE is also working with US government agencies who are asking operating facilities to control the SO_2 emissions in their existing SRU and TGUs to meet 10 ppmv of SO_2. RATE has been helping and designing an additional section for some of these projects. RATE is supporting environmental regulation agencies in the US to control the stack emission in existing facilities. In some cases if the sulphur plant does not have a back-up tail gas unit, they are asked to design the caustic scrubber as a back-up tail gas unit. Many US refineries are being requested to reduce the emission of the existing units by adding a caustic scrubber after the incinerator to replace the stack.

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

The liquid-vapour mixture then flows to the caustic scrubber. The vapour flows up through the packed bed of the caustic scrubber against a countercurrent stream of 10 wt- caustic solution to scrub the remaining SO_2 from the tail gas. The treated gas leaving the caustic scrubber will contain low ppm levels of SO_2.

Due to the temperature of the gas leaving the incinerator waste heat boiler there is a constant vaporisation of water in the caustic scrubber which needs to be made up. This make up water is added to the column at the upper bubble trays to knock any remaining entrained caustic out of the vapour to minimise caustic loss. The caustic system uses a non-regenerable caustic (NaOH in water) to remove the SO_2 from the tail gas. The SO_2 that is removed slowly decreases the caustic strength of the solution so fresh caustic is added to replace this spent caustic. The spent caustic is purged on level control and cooled before being sent off-plot for disposal.

To summarise, using caustic scrubber is another viable option to control the stack emission to less than 10 ppmv of SO_2. Many refineries are required to add a caustic scrubber to their existing units, the cost depends on the sulphur recovery capacity and varies between $5-12 million.

Figure 2 represents the thermal incineration with a caustic scrubber. ■

SHELL GLOBAL SOLUTIONS

Staying ahead of the curve with tail gas treating

The requirement to meet ultra-low SO_2 emission standards, such as lower than World Bank limits, is becoming more and more prevalent for new natural gas developments. At the same time, more complex, sour gas fields are being developed as sweet fields become depleted. Addressing these challenges to ensure that increasingly stringent SO_2 emission limits are met in the future requires technology capable of ultra-high levels of sulphur recovery, even when dealing with difficult gas streams.

Shell Global Solutions has utilised its extensive knowledge and experience of designing and operating Shell Claus offgas treating (SCOT) units since the 1970s to hone the technology for this purpose. The company has also extended its tail gas treating portfolio with the addition of the Shell CANSOLV TGT+ technology. Both these technologies can meet stringent SO_2 emission limits for a range of emission requirements.

Shell CANSOLV TGT+ technology can be applied in an integrated sour gas treating solution. It enables ultra-low SO_2 emissions

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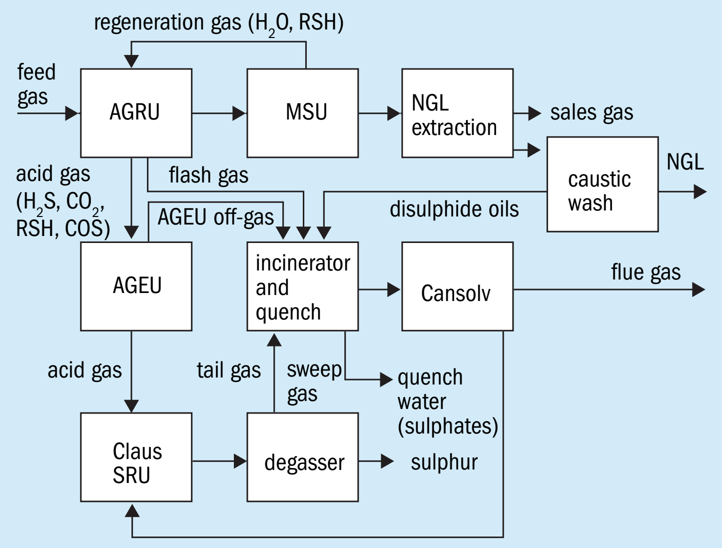
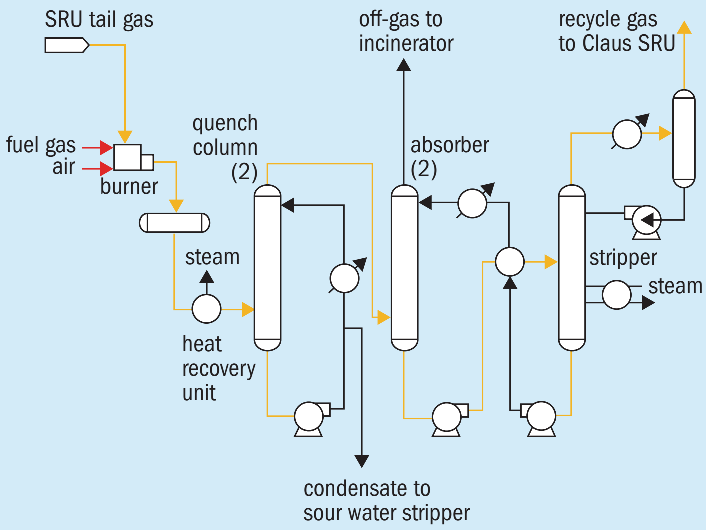
Fig 1: Shell CANSOLV TGT+ process line-up



Source: Shell Global Solutions

Fig 2: SCOT process line-up



Source: Shell Global Solutions

and can capture 99.9+% of the overall sulphur present in sour gas streams while minimising the complexity of the process line-up. This system sits at the back end of the gas processing line-up and serves as the final destination to capture SO_2 from all the plant's sour gas streams routed to the incinerator, as illustrated in Fig. 1.

Figure 1 shows the different off-gases routed to the Shell CANSOLV unit via the incinerator from the acid gas enrichment unit (AGEU) and the degasser. These gases are combined with the flash gas from the acid gas removal unit (AGRU) and disulphide oils generated in caustic treating of extracted natural gas liquids (NGL) or condensate, following treatment in the molecular sieve unit (MSU). Without the Shell CANSOLV technology, each of these individual streams would have required dedicated treatment or would have been emitted to atmosphere after incineration and thus contributed to higher levels of SO_2 emissions.

The Shell CANSOLV TGT+ process centres on the Shell CANSOLV SO_2 scrubbing system, which has been used worldwide to capture post-combustion SO_2 and recycle it back to the thermal stage of a Claus sulphur recovery unit.

"This tail gas treating unit uses a Shell CANSOLV proprietary solvent that can achieve even greater levels of sulphur recovery for more complex applications than conventional SCOT applications. This enables us to be well within the most stringent emission levels mandated in different jurisdictions at competitive capital and operating costs while minimising process line-up complexity," says Dr Lydia Singoredjo, Licensing Technology Manager Upstream Gas Processing at Shell Global Solutions.

"The Shell CANSOLV TGT+ technology's ability to improve on World Bank emission standards gives operators the reassurance that they have a flexible and future-proof technology. Even if you only need to meet a certain limit now, the technology is flexible enough to accommodate future tightening of emission regulations relatively easily. This puts the technology ahead of the curve."

The Shell CANSOLV TGT+ unit is being introduced in several new projects across the Middle East and Europe, where SO_2 emission regulations are very stringent. Some of the projects are now in the construction phase and due to start up soon.

This system has bolstered an already successful tail gas treating technology portfolio. Shell Global Solutions has more than 40 years' experience of designing and operating SCOT units. The SCOT process uses catalytic conversion and amine absorption processes, which are familiar to plant operators, downstream of a Claus unit. The SCOT system can achieve sulphur recovery levels of up to 99.98%.

Shell Global Solutions has licensed more than 300 SCOT units, which has enabled it to build up a strong background in using tail gas treating as a means of meeting SO_2 emission limits. As both a designer and an operator of these units, the company is well equipped with the knowledge and expertise necessary to get the best out of them and offers more than just a design and delivery service. "We have a closed loop whereby we design a unit, operate it and then collate all the operating experience and feed it back into our research and development. We can then feed our research and development results back into our design approach," explains Singoredjo.

"By repeating that loop over and over again, we are always optimising our designs and, ultimately, improving our operations. This knowledge and operational experience are, therefore, vital parts of our technology offer to clients. We know other companies have developed similar versions of the SCOT design, but we have the ability to look back over a history filled with many reference cases and operational and design experience," she adds.

Shell Global Solutions' affiliation with Criterion Catalysts & Technologies, which offers a range of tail-gas treating catalysts, also ensures that the catalyst used in the Shell SCOT technology is continuously improved.

Deciding on which tail gas treating unit to use for a project comes down to the specific project requirements. The heart of the Shell CANSOLV TGT+ system is an absorber and a regenerator, akin to the SCOT unit (see figures 1 and 2).The main difference is that Shell CANSOLV TGT+ unit makes use of a Shell proprietary amine solvent.

"We have a strong portfolio of tail gas treating technologies that can meet and often better regulatory requirements for emissions. Our approach is to look at the entire life cycle of a project and then decide on the best technology fit on a case by case basis," concludes Singoredjo.

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WORLEYPARSONS

Achieving world class performance in sulphur removal technology

S Pollitt

The achievement of world class performance in sulphur removal technology is the result of many inputs and results from access to best in class technology, wide experience of similar design requirements built up over many years and a deep knowledge of operational requirements. Only by applying all these facets will a best in class facility be designed with lowest life cycle costs.

WorleyParsons has been able to achieve these goals by application of its own licensed technology allied to wide experience and knowledge of customer needs.

Minimisation of operating costs

The sulphur recovery facilities at the Habshan 5 complex are considered world class by any standard and will be a model for other sour gas projects around the world. The Habshan 5 sulphur recovery complex is equipped with many unique features including, the largest Claus thermal equipment and the largest FLEXSORB-SE Plus® regeneration systems in the world. The design, start-up and initial operation of these massive facilities required many special considerations and their successful performance testing in late 2013 proved a well-designed plant that will demonstrate robust operation throughout its lifetime.

There exist some opportunities for optimised operation of the Habshan 5 sulphur complex that will provide for reduced operating costs without compromising operational effectiveness. BTX sensitivity testing in U-551 revealed that natural gas consumption in the reaction furnace can be reduced to approximately 25% of the original design value without BTX breakthrough, resulting in the following benefits:

- approximately 30% reduction in natural gas consumption throughout the overall sulphur complex, which is equivalent to $30–40 million in operating cost savings per year;
- freed-up sulphur recovery capacity in the range of 700 t/d, which may prove useful for future debottlenecking requirements;
- nominal reduction in CO_2 emissions from the incinerators.

Integration of process steps

Integration of process design steps to minimise capital and operating costs and reduce emissions to "zero" emissions.

WorleyParsons designed a sulphur removal unit to treat syngas derived from petcoke gasification. The gasification feedstock contained significant quantities of sulphur, which must be removed from the produced syngas prior to utilisation, and due to the presence of CO_2 and contaminants in the syngas, the resulting SRU feedstock was very challenging. Working with WorleyParsons' technology partner, Linde AG, an integrated design was developed using SURE oxygen enriched SRU technology and Rectisol physical acid gas removal process.

Rectisol® is a physical acid gas removal process, which employs an organic solvent (typically methanol) at subzero temperatures to purify shifted, partially shifted or unshifted syngas that emanates from the gasification of raw feedstock containing sulphur. Rectisol® can purify syngas down to 0.1 ppmv total reduced sulphur and CO_2 in the ppm range. Well-known advantages of the Rectisol® process include low utility consumption, use of an inexpensive and readily available solvent, and flexibility in process configuration. Linde has vast experience in designing Rectisol® plants for feedstock containing high sulphur loads, which offer wide flexibility in handling product and byproduct streams. One example of the process' flexibility is its ability to treat tail gas from sulphur recovery units (SRUs), thereby eliminating the need for a dedicated amine system within the tail gas treatment unit (TGTU). Treatment of the SRU tail gas stream in the Rectisol® acid gas removal unit (AGRU) achieves extremely stringent process performance (overall sulphur recovery efficiency in excess of 99.99%), while also reducing capital cost by approximately 15% and operating cost by approximately 30% compared to a conventional approach.

High sulphur recovery rates

The design of modern SRUs requires the achievement of very low emissions of sulphur (99.9+% sulphur recovery). This high standard of operation is achievable but only the best technologies will achieve this at lowest life cycle cost. WorleyParsons looks at each new design in a holistic way to determine the lowest cost and has access to best in class technologies to achieve these goals.

Worley Parsons offers ExxonMobil Research and Engineering Company's (EMRE's) proprietary FLEXSORB® SE process for treatment of acid gas and SRU tail gas. It is well understood that FLEXSORB solvent is highly selective for H_2S, resulting in effective CO_2 slip and extremely efficient H_2S removal, thus making it one of the few technologies of choice when ultra-high sulphur recovery efficiencies are required. What is not always so well understood is the extent of the commercial advantage offered by EMRE's FLEXSORB technology when employed in the right application, irrespective of whether high sulphur removal efficiency is required. This lack of understanding can lead to the propensity for prospective licensees to disregard the technology strictly on the basis of solvent cost, which is known to be greater than that of MDEA.

Unequivocally, solvent cost cannot be used as the sole comparator in a commercial evaluation of gas treating technologies. Rather, all factors affecting capital, operating and maintenance expenditures must be considered in the assessment of facility lifecycle cost. In the appropriate applications, FLEXSORB technology offers commercial benefits that far outweigh its higher solvent cost and render it the most attractive option in many more situations.

In summary, FLEXSORB solvent has traditionally been considered, and should continue to be considered, when any one or more of the following are required:

- ultra-high recovery efficiencies (99.9%+);
- large capacity train sizes (1,000 t/d+);
- high solvent operating temperatures (45-5°C) resulting from ambient conditions and/or cooling water limitations.

In fact, in many of the above situations, FLEXSORB may be the only viable technology alternative that is capable of achieving the performance specifications. In addition WorleyParsons' analysis has revealed that FLEXSORB technology should not only be relegated to technically challenging applications but should also be considered any time acid gas enrichment and/or tail gas treating is contemplated, even in conventional applications with less stringent performance requirements. ■


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- Oscar D., WorleyParsons Mechanical Engineer, USA
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Sour to power

A study has been carried out to investigate the feasibility of using sour gas from the processing of sour crudes and sour (associated gas) for power generation as an alternative to Claus-based gas processing. The study concluded that the ‘Sour-to-Power’ concept is technically feasible but economically challenging. For a Sour-to-Power based field development to be successful it would require the participation of an upstream or integrated company, a power company, the sulphuric acid consuming industry and governments to provide suitable commercial terms and conditions.

In an increasing number of countries in the world, it may be increasingly challenging to meet gas production and (LNG) export commitments. Domestic power demand is ever increasing due to population growth, increasing living standards and industrial development. Countries may be forced to import fuels like oil or diesel while subsidising internal power generation and transport fuels. Or, oil-fired power generation may limit the amount of oil available for export.

At the same time, easy gas resources have been developed already, forcing countries to develop more complex and, hence, more expensive, resources, like tight gas or (highly) sour gas. This article focuses on an alternative way to develop the latter type of gas fields. Conventionally, sour gas is processed to produce a sales gas quality fuel gas for power generation. The upstream gas processing is complex and expensive, leading to high unit development costs (UDC). As an alternative, one may consider using the sour gas as a sour fuel gas for power generation, i.e., Sour-to-Power (S2P). This would lead to a shift of UDC from upstream gas production to power generation since all sulphur would need to be captured from the power plant’s flue gas, the latter enabled by SO_2 capture technologies like the commercially available and proven Shell Cansolv SO_2 scrubbing system. Also, combusting sour gas may have consequences for power generation costs and efficiency.

The potential advantages for a S2P scheme over a conventional AGRU-Claus-SCOT scheme are:

- reduced capex since no sales gas at stringent specifications needs to be produced;
- reduced upstream plant complexity;
- reduced sulphur emissions since end-of-pipe sulphur capture at the power plant;
- higher power output since a larger part of the energy present in the H_2S contributes to power production (as demonstrated in Fig. 1).

Potential drawbacks are:

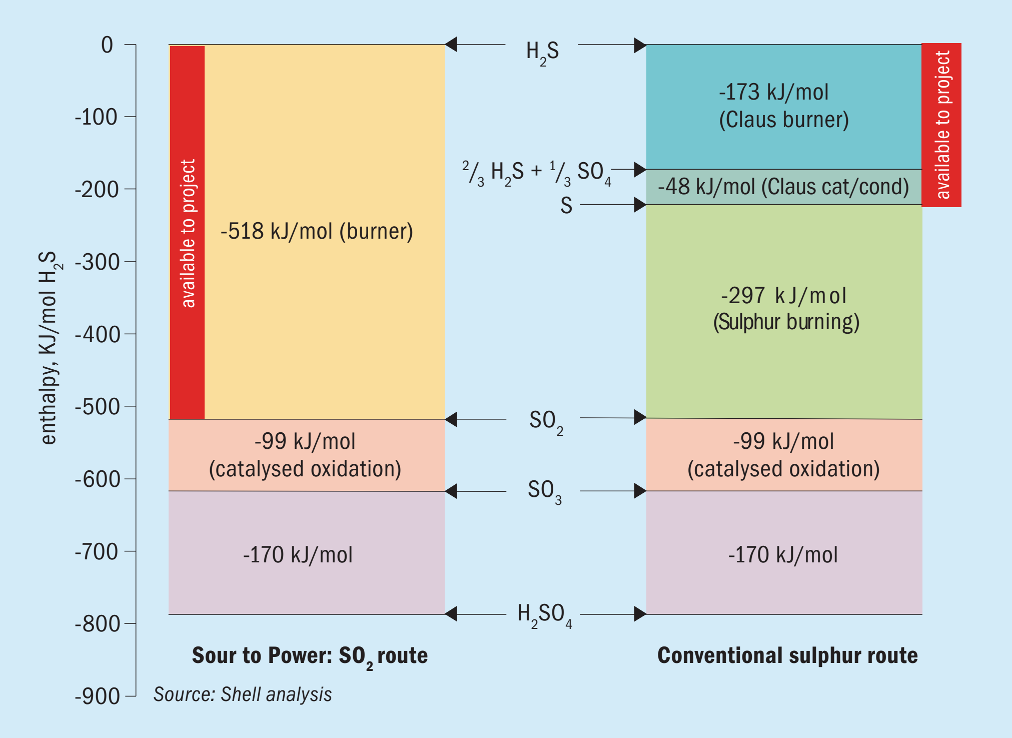
- no elemental sulphur as a marketable product, but SO_2 as a product that requires further processing;
- gas treating moves from high-pressure upstream to atmospheric pressure flue gas desulphurisation, hence, lower driving forces for mass transfer and more voluminous equipment;
- the sulphur containing gas stream may now also contain inert nitrogen, hence, a diluted and more voluminous stream would need to be treated.

This article provides the results of a study that was executed to reach a conclusion on the technical and economic feasibility of such a Sour-to-Power field development concept. The study included the costs for wells, upstream facilities, power production (various schemes), flue gas desulphurisation and conversion of sulphur dioxide into sulphuric acid.

Power generation technologies considered were:

- subcritical thermal boilers with steam turbines;
- supercritical boilers with steam turbines;
- combined cycle with gas turbines (CCGT);
- Shell technology option 1 (under review);
- Shell technology option 2 (patents pending).

Fig 1: **Reaction enthalpies involved in staged conversion of H_2S into H_2SO_4**



Source: Shell analysis

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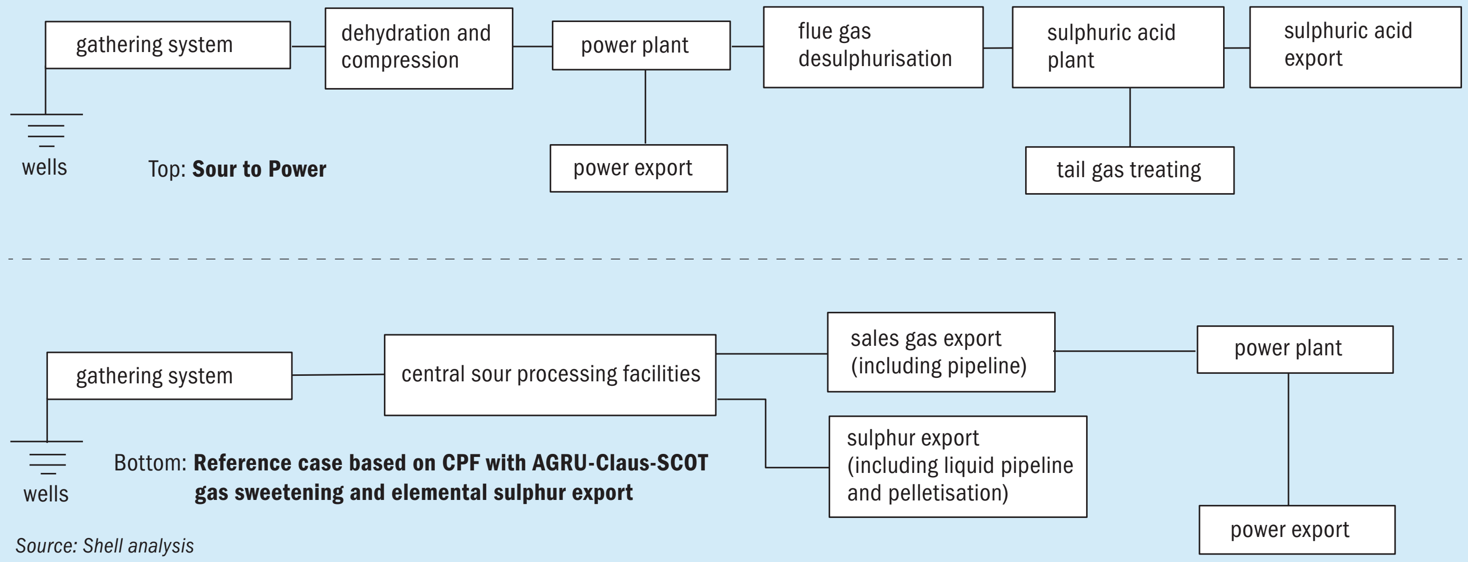
Fig 2: **Schematic scope included in economic evaluation**



Source: Shell analysis

Study set-up

Overall value chain

The S2P concept was reviewed for a hypothetical highly sour gas field with 33% of H_2S and a raw gas production rate of 500 million std ft³/d (589,934 m³/h). In order to consider the full value chain, from subsurface to power generation and sulphuric acid production, the costs for upstream facilities, various power plant concepts and downstream facilities were included in the analysis (see Fig. 2, top, for a high-level block diagram).

The upstream facilities included:

- wells, based on carbon steel;
- gathering system (20 bar);
- inlet separators;
- sour gas dehydration;
- sour gas compression (only for power generation schemes that require higher than 20 bar fuel gas pressure);
- sour gas pipeline.

The downstream facilities included:

- flue gas desulphurisation (FGD, Cansolv technology), including flue gas pre-treatment (flue gas blower, wet electrostatic precipitators (WESP), quench tower);
- SO_2 conversion into sulphuric acid (wet sulphuric acid process);
- sulphuric acid plant off gas treating (also Cansolv technology);
- sulphuric acid handling facilities.

Estimating the total installed costs for the quench tower, WESP, Shell Cansolv system, sulphuric acid plant and off gas treating were outsourced to an independent third party. The costs for all other items (except for power generation) were estimated internally by the Shell front-end design department. Sulphuric acid handling costs were assumed equal to elemental sulphur handling costs.

The conventional AGRU-Claus-SCOT route served as the reference (see Fig. 2, bottom, for a high-level block diagram).

The upstream facilities for the conventional route included:

- wells, based on carbon steel;
- gathering system (20 bar);
- inlet separators;
- acid gas removal units (solvent plant);
- Claus unit;
- sulphur handling facilities;
- SCOT unit;
- sweet gas dehydration;
- sweet gas compression (to 45 bar export pressure);
- sweet gas export pipeline.

The power plant was combined cycle with gas turbines (CCGT), on sweet fuel gas.

All costs for the conventional route (except for power generation) were estimated internally by the Shell front-end design department.

SO_2 outlets

Sour-to-Power results in conversion of all sulphur species into SO_2 for which outlets need to be found Hence, a market study looking for potential SO_2 outlets was outsourced to an external market research service provider to generate basic data from public sources.

Conversion of SO_2 to elemental sulphur was not in scope since that option would combine a high need for chemicals or the combination of extensive upstream facilities (to generate, e.g., a sweet gas that could serve as a reducing agent or an H_2S stream that would enable the Claus reaction) and downstream facilities (to generate the concentrated SO_2). Also, SO_2 injection into the subsurface was not in scope due to high subsurface uncertainties (e.g., due to potential subsurface Claus) involved.

This study revealed that sulphuric acid is the only viable SO_2 outlet for sizable sour gas developments.

Power generation: Conventional options

Various conventional power generation technologies were considered, each having their specific (total installed) capex requirements and delivering power at a specific efficiency, as listed in Table 1. In discussions with vendors, no showstoppers for applying sub or supercritical boiler systems or gas turbines were identified. It is important to note that, unlike what would be realistic for fuel oil, a clean sour fuel gas was assumed, not containing any sand, salts, liquids or ash-generating components. Proper upstream phase separation is essential to justify this assumption. Also, proper inlet air conditioning was assumed, especially, to remove any chlorides that would cause severe corrosion. This would imply the installation of suitable inlet air filters. Under these conditions, vendors confirmed that Sour-to-Power is technically feasible for any H_2S concentration, for boiler systems as well as gas turbines.

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- Permanent licensee of **DuPont™ - MECS®** for major integrated units
- **Proprietary technology and know-how** (with DuPont™ - MECS® catalyst and components) for smaller units (up to 200 TPD)
- **Wide range of configurations** available in relation to converter stages, heat integration (MECS HRS™), electric power production (STG backpressure or condensing) and other components to meet specific project needs
- **Design capabilities** for a wide range of feed-stocks: sulphur burning, wet gas stream (DuPont™ - MECS® Sulfox™), metallurgical and the like
- **Experience** in SO_2, SO_3 and oleum production
- **Tail gas cleaning systems** including DuPont™ - MECS® Dynawave™, scrubber (e.g. soda or peroxide) and other systems
- **Flexibility** in defining the most appropriate project execution scheme to meet Client requirements
- **Skills** in relation to both new SAP units and upgrading of existing SAP installations by new sections or modifications
- **Compliance** to the most stringent environmental requirements (BAT, emissions, efficiency and the like)
- Worldwide **after sales technical support**

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Gas turbines (GTs) operate at high excess air rates to control the combustion temperature (materials considerations and NO_x control). The study indicated that the flue gas volume from gas turbines will be roughly four to five times larger than the volume generated by thermal systems (fired boilers) for the equivalent LHV fuel amount. This has two important consequences for the flue gas desulphurisation downstream gas turbines:

- equipment needs to be designed for higher flue gas volumes (hence, more capex);
- the SO_2 concentration in the flue gas is 4 to 5 times lower for gas turbines, while the total amount of sulphur to be captured remains equal. This gives a lower cyclic loading of the Cansolv amine solvent, which leads to a higher steam demand in the regenerator.

The lower efficiency for CCGT with a sour fuel, as indicated in Table 1, is the consequence of three issues:

- gas turbine vendors indicate they will not utilise their highest efficiency (highest temperature) machines but a lower class robust design;
- gas turbines in sour operation will experience a somewhat higher back-pressure due to the downstream Cansolv flue gas desulphurisation (including flue gas pre-treating);
- the efficiency of 47% vs 52% for sour CCGT vs sweet CCGT was estimated by assuming a stack temperature of 250°C for sour vs 100°C for sweet, which was assumed to only affect the steam cycle. A high stack temperature would be required to prevent condensation of sour components in the heat recovery systems (boiler or HRSG).

The same penalty of 5% points for CCGT was also assumed for sweet vs sour boiler performance.

All evaluations were based on the assumed model sour gas composition shown in Table 2. To generate a composition for the flue gas from Sour-to-Power, the combustion of this sour gas composition was modelled using a proprietary model. The resulting flue gas had a residual oxygen content of 2%, which is valid for conventional thermal combustion in boiler systems (sub or supercritical). It was assumed that 1% of all SO_2 formed would be converted into SO_3, thus, obtaining a sulphur dew point for the flue gas of around 190°C. In calculating the resulting heat (efficiency) loss, a minimum stack temperature of 250°C was assumed.

Table 1: **Power generation efficiencies and total installed capex (relative to base case CCGT on sweet fuel gas) for various well-proven standard power generation types**

Power generation type	Best reported efficiency, ISO conditions, pipeline gas (% of LHV fuel gas)	Assumed actual efficiency (% of LHV fuel gas)	Assumed relative capex per kWe installed
Direct fired subcritical boiler with steam turbines	35	30	1.25
Direct fired (ultra) supercritical boiler with steam turbines	42	37	1.25
CCGT sweet fuel gas	61	52	1.00
CCGT sour fuel gas	n/a	47	1.00

Source: Shell interpretation of various internal and open literature data

Table 2: **Assumed model sour gas data (after dehydration)**

Property	
Volume flow, million std ft³/d	500
Mass flow, kg/s	209
LHV, MJ/kmol (MJ/kg)	638 (26)
Component	
CO_2, mol-%	9.5
H_2S, mol-%	33
N_2, mol-%	0.4
CH_4, mol-%	56
C_2+, mol-%	1.1

Based on the steer from discussions with vendors, to generate a flue gas from gas turbines, the flue gas composition obtained for thermal systems was diluted with air to obtain a flue gas with 17% residual oxygen, thus, accounting for the high excess air factor (~4) that gas turbines require to deliver power at high efficiency.

Power generation: Shell technology options 1 and 2

In addition to the power generating technologies listed in Table 1, two alternative power generation options were also included in the evaluations. In essence, these technologies generate a flue gas under exclusion of nitrogen from combustion air. A Shell internal experimental programme demonstrated the technically feasibility of technology option 2.

For technology option 2, a supercritical steam cycle was assumed to drive the power generator. To prevent condensation of corrosive components in the heat recovery system, a high stack temperature would be required. However, in this case, the flue gas volume and, hence, the heat losses, are a factor four to five smaller due to the absence of nitrogen. Hence, the effect of a high stack temperature was neglected and state-of-the-art supercritical boiler efficiency was assumed (Table 3).

In both technology options, the flue gas is sufficiently concentrated in SO_2 to feed directly into a sulphuric acid plant. Hence, no Cansolv SO_2 capture plant was included in the cost estimates, other than off-gas treating downstream the acid plant.

From the gross power production, based on fuel gas LHV and mass flow, penalties were deducted to account for internal power consumption.

The fuel demand by the conventional upstream facilities was estimated to be 7% of the sweet gas produced. This translated into an electrical power penalty of 7%.

The power penalty for the Cansolv unit was calculated from the LP steam demand quoted by Cansolv. No flue gas clean-up is required for the CCGT power plant running on pipeline gas. Steam produced in the sulphuric acid plant was deducted from the steam required by the Cansolv units.

The flue gas desulphurisation train pressure drop was assumed to be 10 inch water column, for which a blower power penalty was deducted.

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47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84

Table 3: **Power generation efficiencies and total installed capex (relative to base case CCGT on sweet fuel gas) for Option 1 and 2 power generation types**

Power generation type	Best reported efficiency, ISO conditions, pipeline gas (% of LHV fuel gas)	Assumed actual efficiency (% of LHV fuel gas)	Assumed relative capex per kWe installed
Power generation option 1	59	52	1.00
Power generation option 2	42	42	1.25

Source: Shell interpretation of various internal and open literature data

CCGT cases and power generation Option 1 require a fuel gas pressure of 45 bar. Power penalty calculations were based on compressor feed conditions of 18 bara (gas gathering at 20 bar) and 70°C. An adiabatic efficiency of 75% was assumed. Thermal cases and power generation Option 1 require 5 bar fuel gas pressure, hence, no upstream compression power was included.

Flue gas desulphurisation

Flue gas desulphurization (FGD) was based on Shell Cansolv SO_2 capture technology, which is based on an SO_2-selective amine solvent. Figure 3 provides a schematic drawing of the technology. A water quench and WESP are required upstream of the Cansolv absorber, in order to properly prevent contamination of the solvent and manage the inlet gas temperature.

Sulphuric acid plants, based on the wet sulphuric acid process, accept SO_2 concentrations in the range of 3 to 20%. A sensitivity study demonstrated that the optimum will be around 12% SO_2. The Cansolv plant was designed to produce a 92.5% SO_2 stream (balance water), assuming 100% SO_2 recovery, with a by-pass to produce 12% SO_2 in the feed to the acid plant.

The steam consumption by the regenerator was deducted as a penalty in the power generation calculations.

Conversion of SO_2 into sulphuric acid

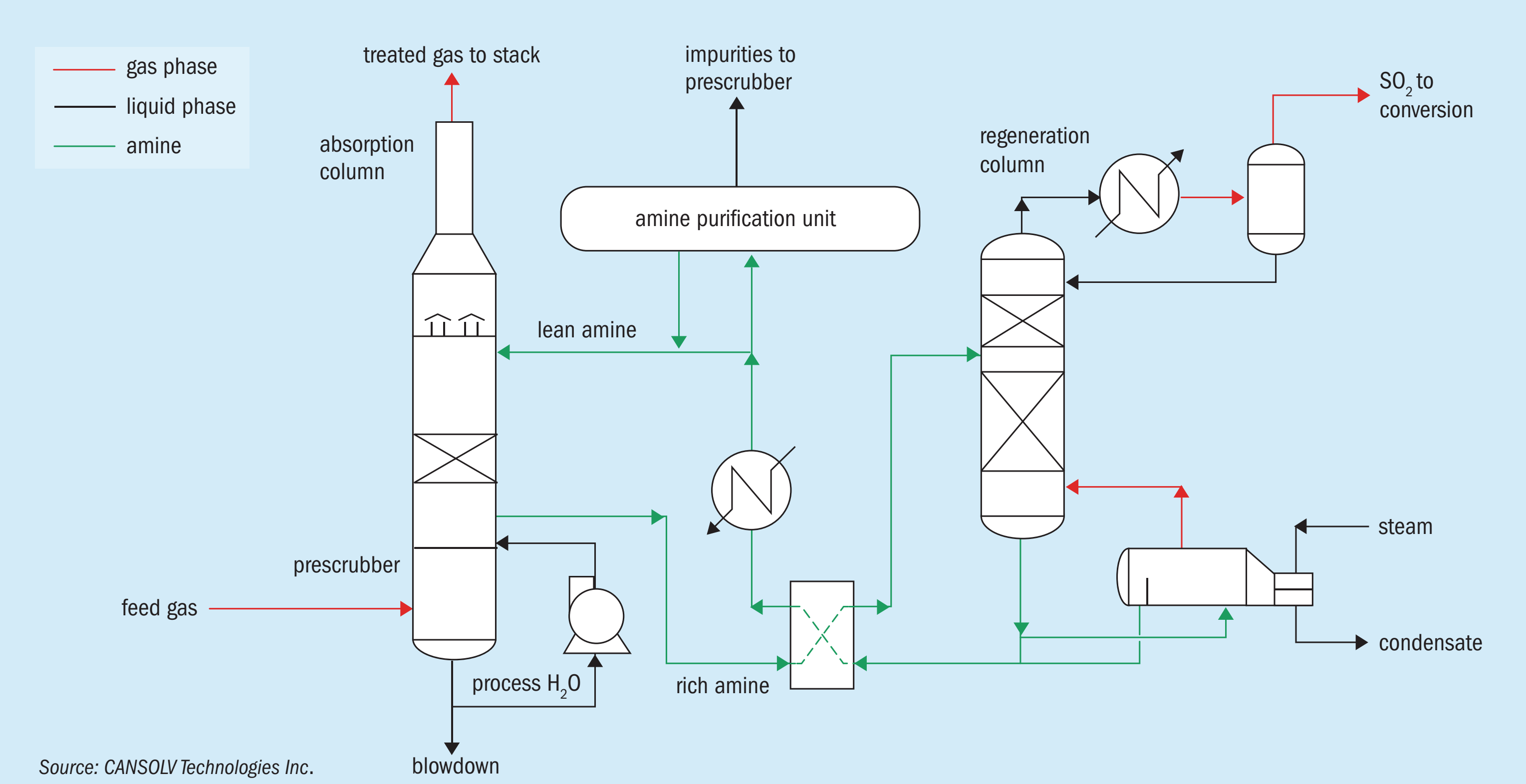
For the conversion of SO_2 into sulphuric acid (H_2SO_4), the wet sulphuric acid process was assumed. A cost estimate was provided by an independent third party. This cost estimate was used for all cases since the total sulphur load is equal for all cases. It was assured that the feed into the acid plant had an O_2/SO_2 ratio of at least 0.75 to allow for proper oxidation of SO_2 to SO_3.

Economic modelling

The economics ($/MWh), in terms of capex and long run marginal costs (LRMC) for the power produced, was estimated for the following cases:

- Base: Sour conventional base case with CCGT on pipeline gas (<20 ppmv H_2S, <5% CO_2);
- Sub: S2P with sour subcritical boiler;
- Super: S2P with sour supercritical boiler;
- CCGT: S2P with sour CCGT;
- T1: S2P based on Shell Technology Option 1;
  - T1A: with a Cansolv off gas treating unit;
  - T1B: without any off gas treating;
- T2: S2P based on Shell Technology Option 2;
  - T2A: with a Cansolv off gas treating unit;
  - T2B: without any off gas treating.

Fig 3: **Shell CANSOLV schematic process scheme**



Source: CANSOLV Technologies Inc.

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Fig 4: **Net power available for export**

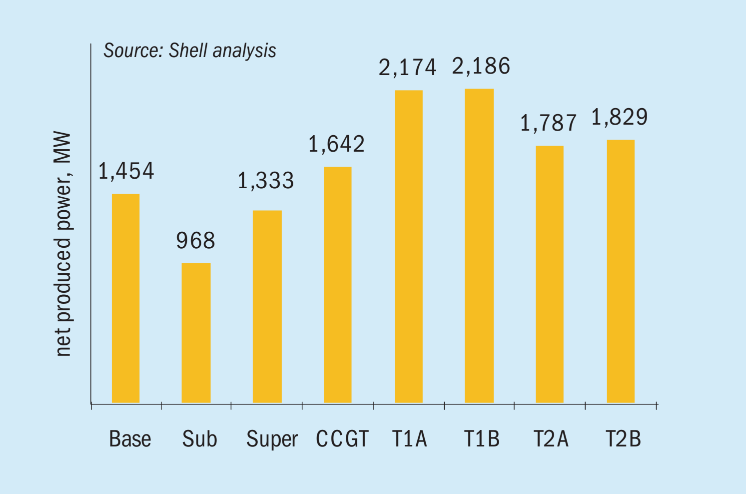
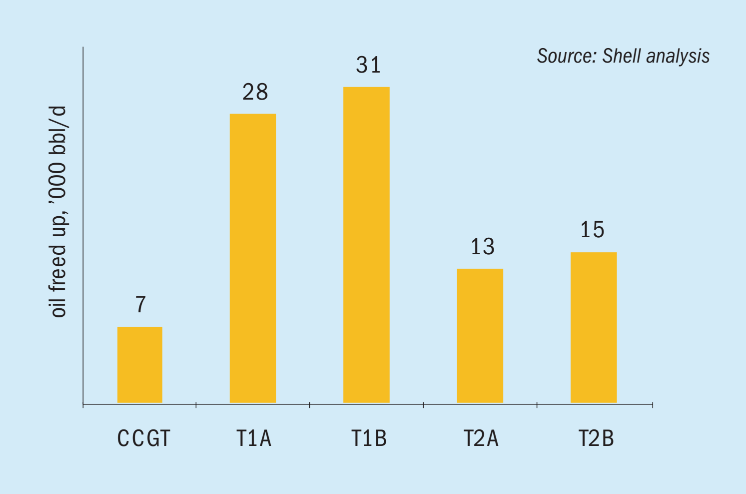


Fig 5: **Potential free-up of oil from higher net power production**



The T1A/B and T2A/B cases were introduced to account for potential closed-loop type systems that may not require additional off gas treating.

The following economic model parameters and assumptions were used:

- lifetime of upstream facilities, power plant and FGD facilities is 20 years after first gas;
- capex spent up to 1st gas was depreciated linearly over a period of 20 years;
- capex spent during the production phase, i.e., capex for additional wells and gathering system to hook up new wells, was depreciated in a faster pace to ensure full depreciation at the end of the 20 years production period;
- base case economics: value over investment ratio VIR=0.2, availability factor AF=0.8 and no costs related to CO_2 emissions;
- power and sulphuric acid required revenues were calculated to meet the VIR of 0.2 at a discount rate of 7%;
- corporate income tax of 30% was included as costs on profit;
- OPEX (O&M) was estimated as 1.5% over wells, gathering system and pipelines and 3% over all other capex components (not depreciated, not discounted);
- project did not borrow any money, hence no interest included as additional costs (ungeared model);
- no royalties to country included in costs.

In the Sour-to-Power cases, the TEG unit and compressors process sour feed gas, requiring more stringent materials, and a higher gas volume (due to the H_2S). This was accounted for by a factor 3 higher capex for these components, relative to the sweet case.

Although very dissimilar activities, sulphuric acid handling in this first approach was assumed to require the same capex as elemental sulphur handling. Further work would be required to detail this. For now, favourable sensitivities (± 30%) on FGD capex requirements would cover the uncertainty.

Results and discussion

Power production

Figure 4 shows the net power available for export for the various cases. From these data, it is concluded that:

- for the subcritical boiler case (Sub), the H_2S LHV does not compensate for the loss in efficiency compared to CCGT on sweet gas (Base);
- for the other cases, a higher net power production compared to CCGT on sweet gas (Base) can be expected due to the combined H_2S LHV and attractive efficiency.

Depending on the specific local situation, the higher power production may translate into additional benefits like revenues from additional oil that is freed up for export. Figure 5 translates the delta in power output of the sour to power cases compared to base case into Barrels freed up from combustion in an oil-fired subcritical thermal power plant, assuming a power plant efficiency of 30% on an LHV of 43 MJ/kg at an oil density of 858 kg/m³.

Capex

The total installed costs for the value chain (subsurface to power and sulphuric acid) heavily depends on the amount of flue gas that is generated. Figure 6 clearly indicates the differences in that respect between the various power generation technologies.

It should also be noted that a higher gross power production (function of

Fig 6: **Flue gas characteristics for various power generation technologies**

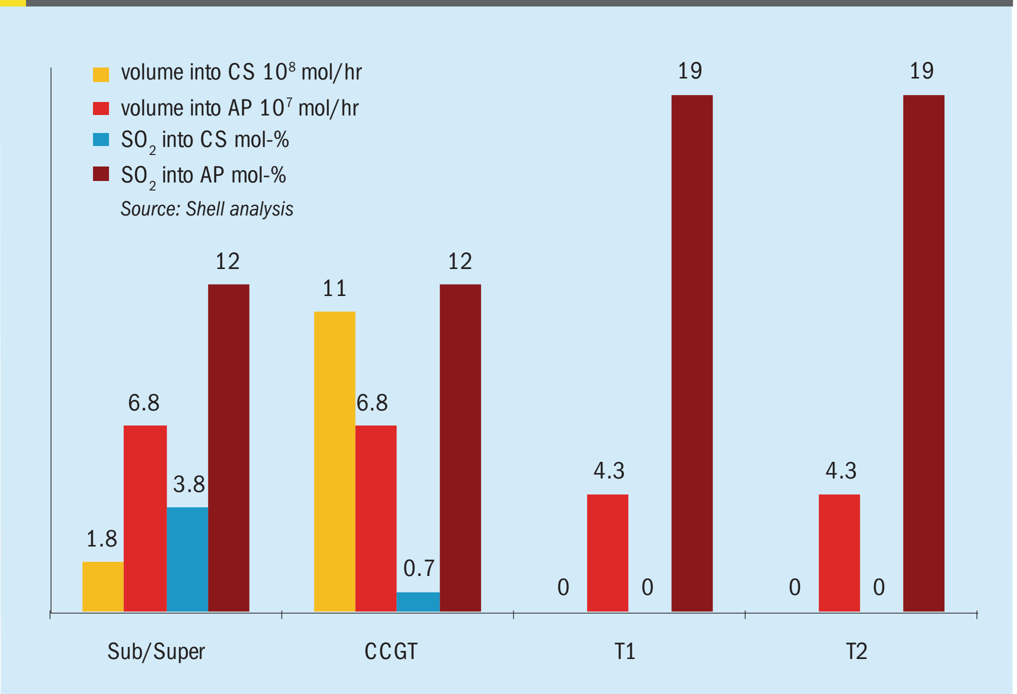



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Fig 7: **Total installed capex relative to base case**

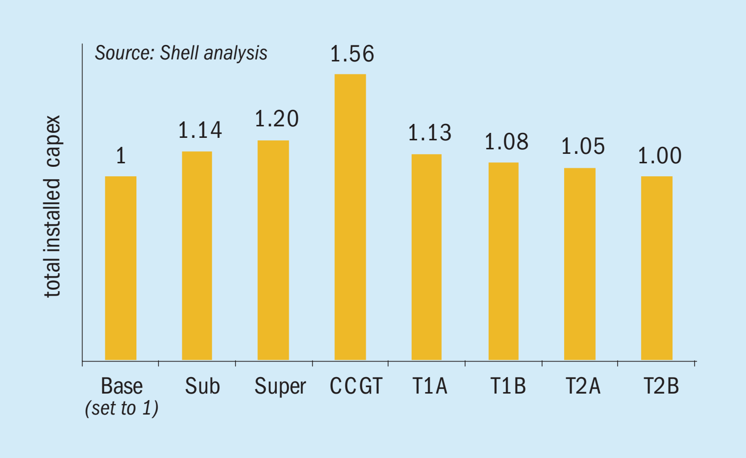


Fig 9: **Relative total installed capex/MW net power production**

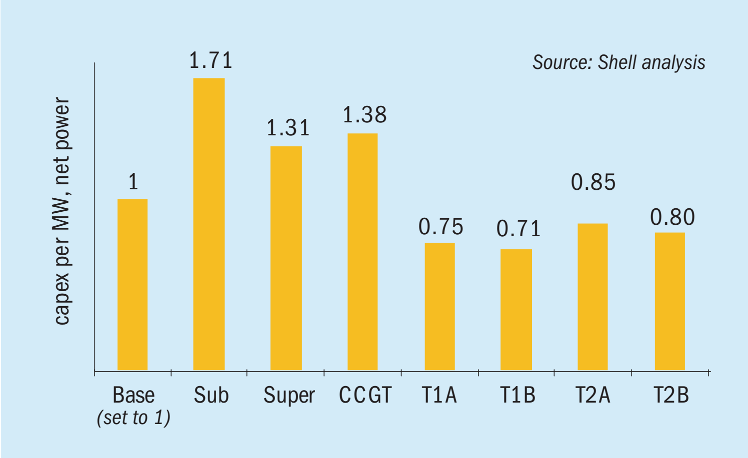
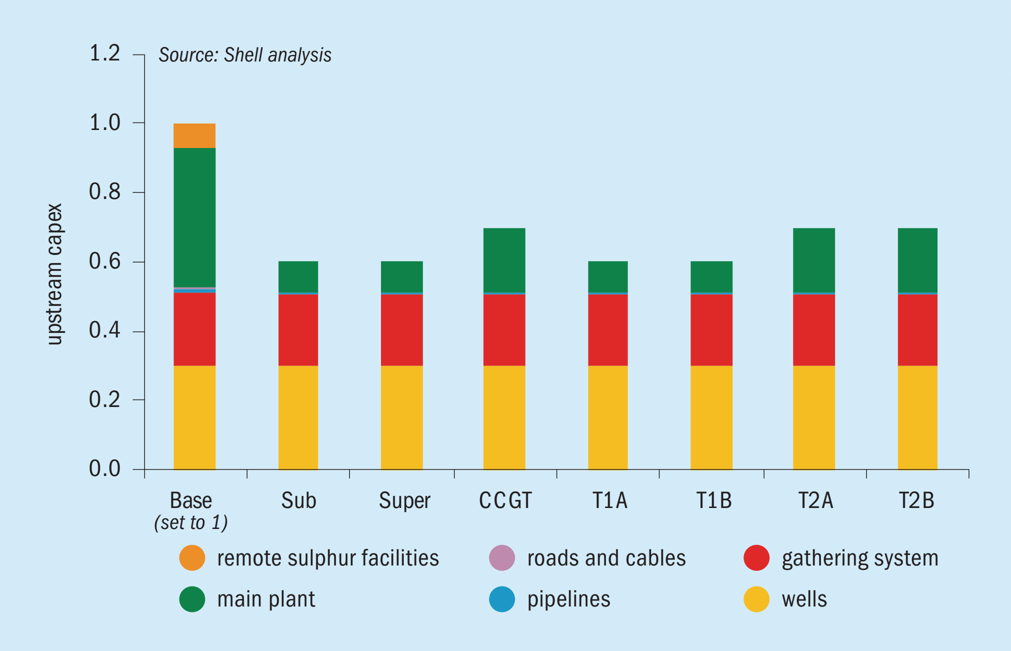


Fig 8: **Relative upstream capex**

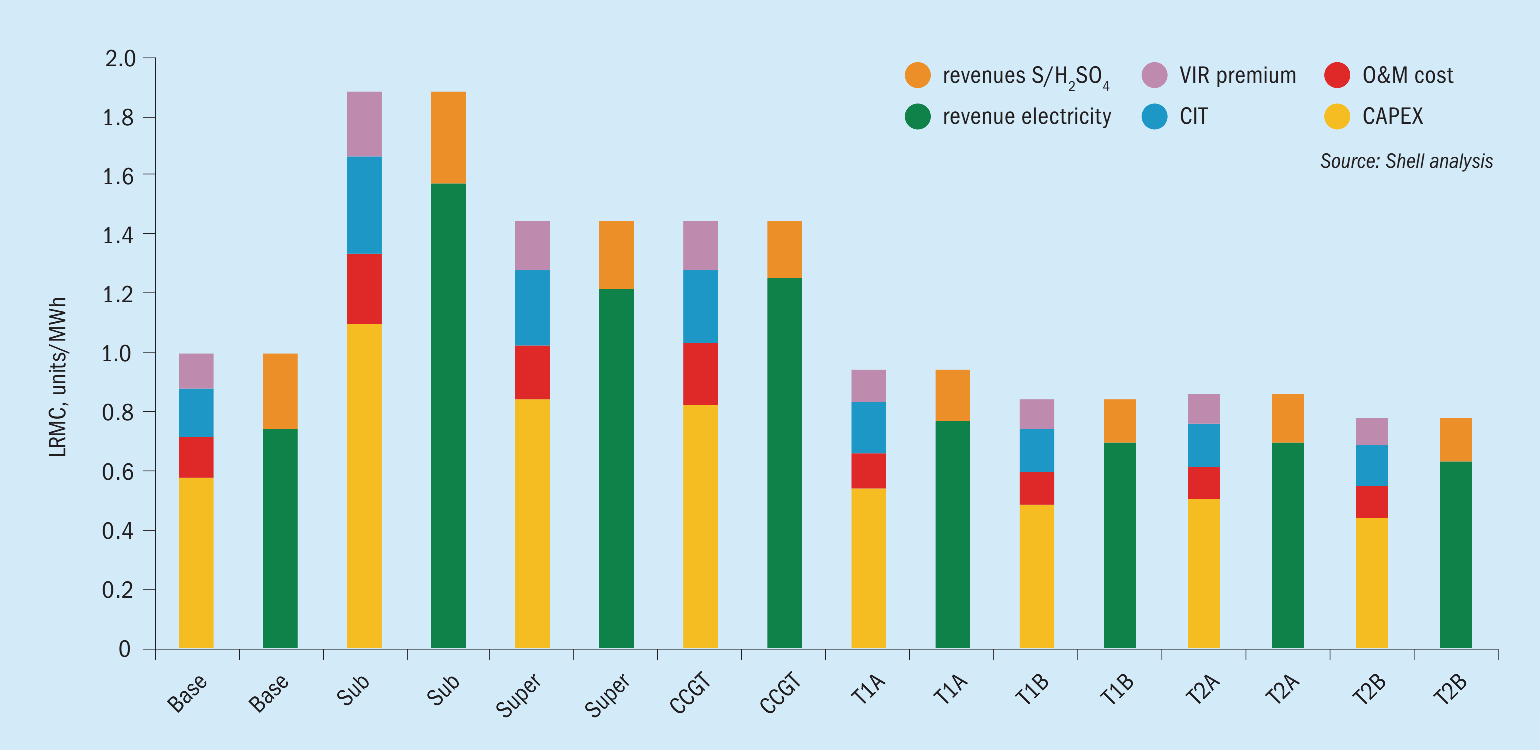


heating value, power penalties and power production efficiency) is penalised in terms of capex since the power plant capex is linearly proportional to the gross power (as indicated in Tables 1 and 3).

With the above in mind, the relative total capex requirements (Fig. 7) for the various cases can be easily understood: The T1 and T2 cases ask more capex because of the high gross power production, which determine the size of the power plant. The Sub, Super and CCGT cases demand high capex through their high flue gas volumes that require large FGD facilities.

As expected, though, the capex savings for the upstream company are significant, 30-40%, depending on required fuel gas compression, as indicated in Fig. 8, which allows the upstream company to produce against a lower UDC. From a complete

Fig 10: **Long run marginal costs relative to base case**



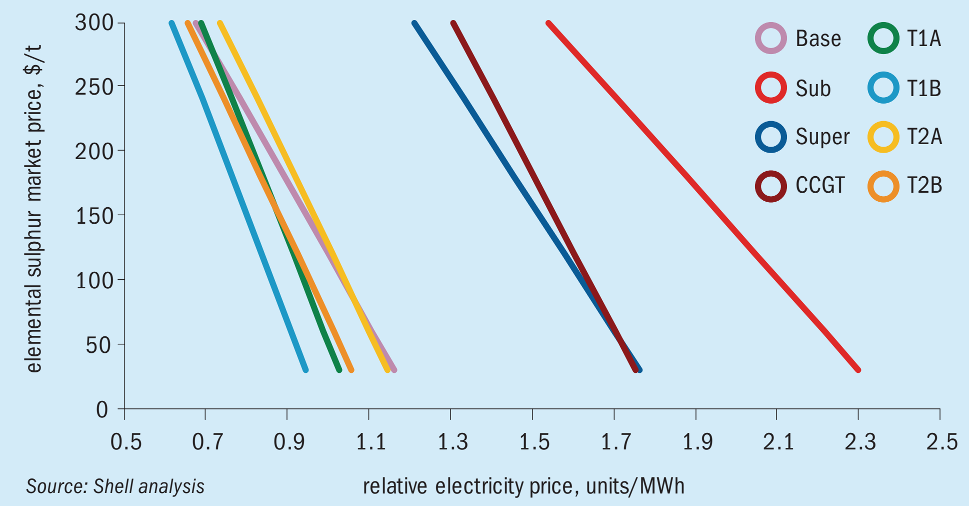
value chain perspective, Figure 9 indicates the relative installed capex per MW net power production capacity. This plot learns that the Sub, Super and CCGT cases are relatively expensive and need to be advantaged by additional revenues, like freed-up oil, a CO_2 product stream for EOR, or subsidies and, therefore, may be very niche applications. Interestingly, the innovative T1 and T2 schemes are economically attractive with potential capex /MW reductions in the range of 15-30%.

Economic modelling

The results from the full economic modelling are shown in Fig. 10. This figure shows pairs of bars. The left bar is the costs bar. The right bar shows the revenues, taking the elemental sulphur ($30/t) or the sulphuric acid ($10/t) revenues as a given and calculating the required power price to match the costs, thus, producing the desired VIR for the chosen economic parameters and assumptions. Overall, this figure reflects the conclusions on capex and net power production capacity.

Figure 11 shows the sensitivity of power price towards the sulphur revenues. More revenues from sulphur or sulphuric acid sales justifies a lower price for the power. Alternatively, for a fixed power price, the required sulphur revenues can be determined. This plot does not take into account additional potential revenues like oil freed up for export or CO_2 available for sales. Based on this plot, for a given power price, a required sulphuric acid revenue can be determined, based on which a market study can be done to determine the potential sulphuric acid market contracts that can be developed at that price.

Fig 11: **Electricity price as a function of sulphuric acid revenues to realise a value investment ratio (VIR) of 0.2 relative to base case**

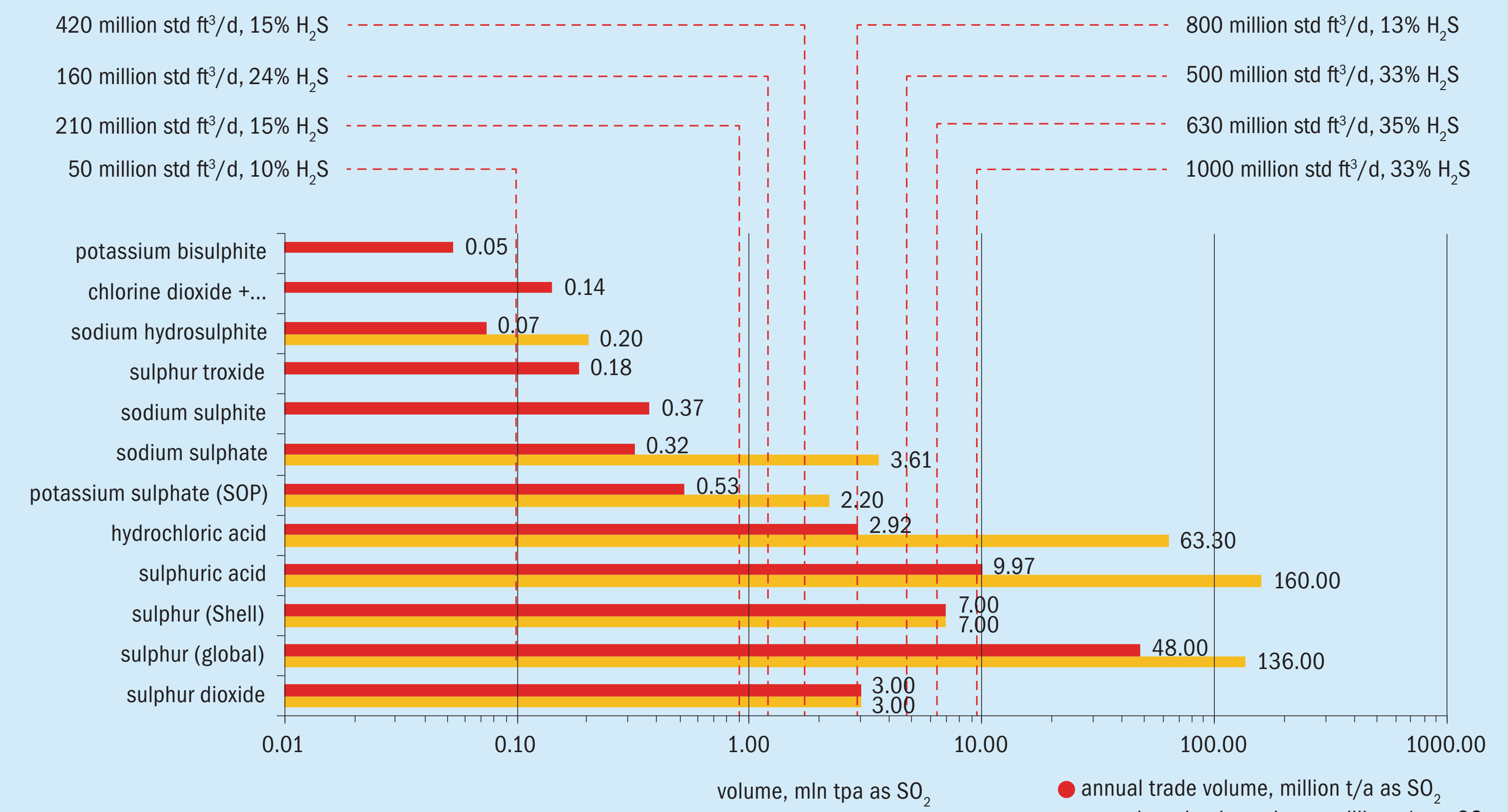


Source: Shell analysis

SO_2 outlets

In the SO_2 market study, it was concluded that the sulphuric acid market is the only market that may be sufficiently sizable to absorb the amount of sulphuric acid produced in any Sour-to-Power operation. This is clearly demonstrated by Fig. 12, which, for comparison, also plots the current global elemental sulphur market.

Fig 12: **Potential SO_2 annual trade outlets and annual production volumes vs SO_2 production of potential sour gas projects**



Source: Shell interpretation of data provided by Avalon Global Research

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In order to understand the future potential of the sulphuric acid market, Figure 13 plots the development of production over 2006 to 2011, together with the potential production from a very large S2P development. The average annual growth over this period was 10 mln t/a, hence, adding roughly one sizable S2P production volume each year.

The sulphuric acid price development over the same period is shown in Fig. 14. The acid price follows the global elemental sulphur price, corrected for the difference in molar weight.

Sulphuric acid is mainly consumed to produce phosphate fertilizer for agriculture (Fig. 15). Though product diversification may help to market all sulphuric acid from a S2P operation, a significant part will have to be absorbed by the phosphate fertilizer industry.

Due to the need for large volumes of phosphate rock, a fertiliser manufacturing plant is usually located near the rock reserves. The largest global phosphate rock reserves are in Morocco, China, Jordan, South Africa, USA and Kazakhstan. Significant mining capacity is on-stream in and around the Middle East, with significant planned expansions in Morocco, Algeria, Syria, Tunisia and Saudi Arabia. The potential for full scale very sour S2P developments is large when considered alongside the potential for phosphate mining capacity growth.

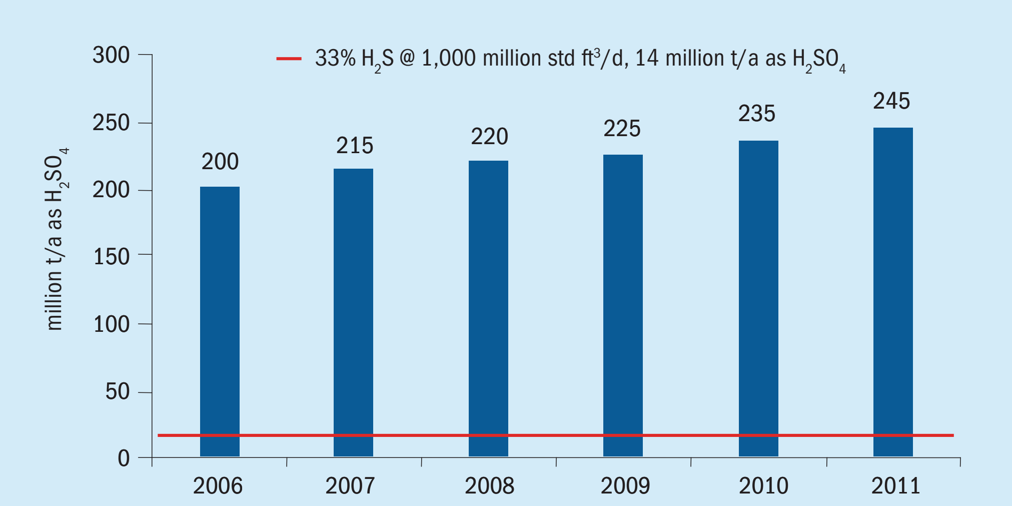
In conclusion, any S2P operation will produce significant volumes of SO_2 that needs to be absorbed by the global SO_2-based (or sulphur based) markets. The majority of SO_2 produced will need to find its way, via sulphuric acid, to the phosphate fertiliser industry, which relies on the presence of phosphate rock reserves or transport to these reserves.

Hence, Sour-to-Power is a concept that requires niches of moderate scale and a geographical fit between sour gas development and phosphate rock reserves. Since the fertilizer industry is such significant factor in the concept, a successful development should include such industrial party as a partner.

Reference

1. van der Vaart R, Wroblewicz T, Gosselin M, Shaw D, Spencer A, Steimel W, John R, Meijerink M, Chan K and Smit K: "Sour-to-Power as an alternative to Claus-based gas processing", written for Sulphur magazine.

Fig 13: Development of sulphuric acid annual global production rate



Source: Shell interpretation of data provided by Avalon Global Research

Fig 14: Quarterly sulphur and sulphuric acid prices

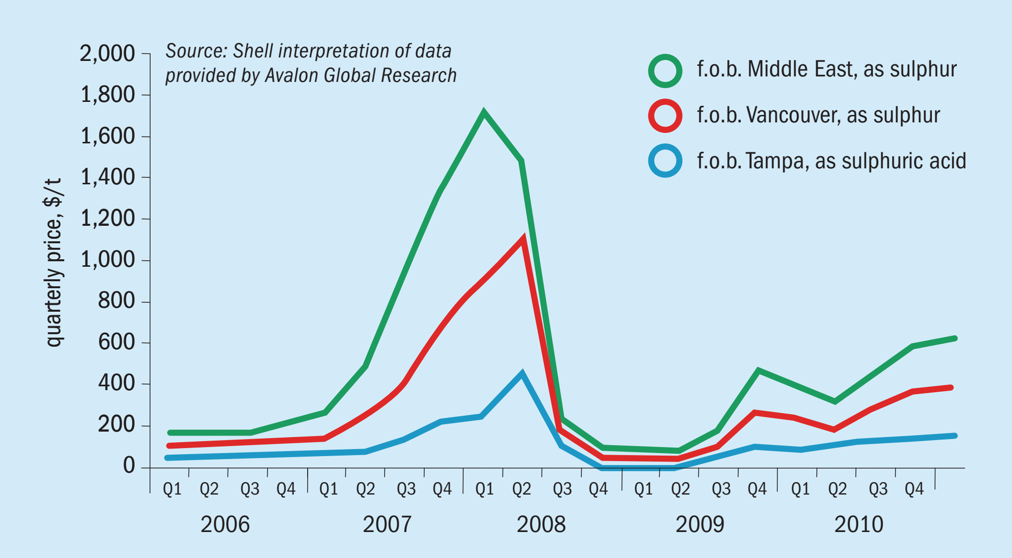
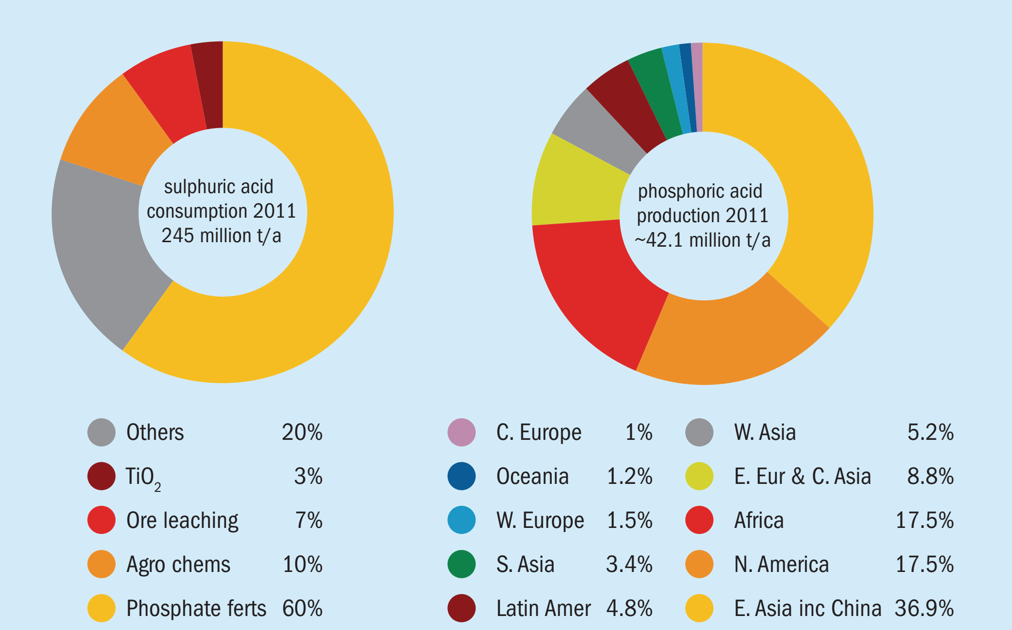
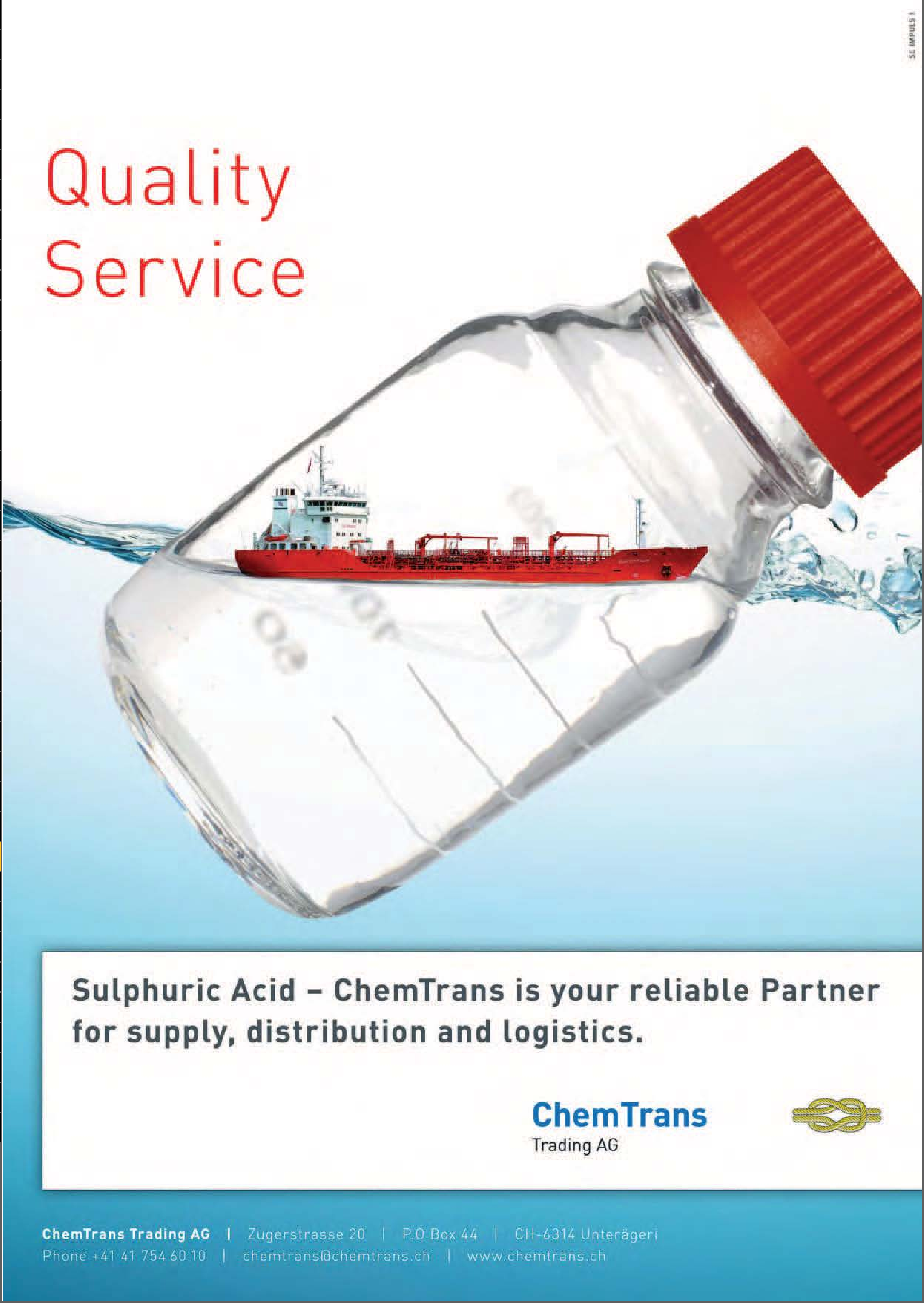


Fig 15: Sulphuric acid consumption and phosphoric acid production



Source: Shell interpretation of data provided by Avalon Global Research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A bigger future for SX™

Outotec Edmeston SX™ steel is a well established material in sulphuric acid plants. For decades it has been used for piping, acid distributors, acid coolers and towers. **K. Daum** and **R. Hagman** of Outotec report on the history and performance of SX™ to date and describe the latest developments to extend its application in future to even larger sulphuric acid plants and for locations with severely limited or no water availability.

The sulphuric acid production process is well established and has changed little since the double absorption process was introduced in the early 1960s. However, many substantial and important developments have taken place to improve efficiency, prolong lifetime and increase plant safety. These advancements have led to industry demand for more appropriate construction materials. To meet these needs, Sandvik first started to develop a silicon containing stainless steel for use in hot sulphuric acid in the early 1970s and SX™ was commercially introduced to the market by Edmeston in 1984. Edmeston SX® has played an important part in the efforts to reduce corrosion, prolong equipment life and increase safety in sulphuric acid plants. The experience gained through a long and close cooperation with plant operators has resulted in ongoing development and improvements in equipment design.

In 2010 Edmeston was acquired by Outotec, a leading sulphuric acid plant designer with over 600 plants corresponding to more than 30% of the world production capacity.

What makes Outotec Edmeston SX® steel special?

Outotec's proprietary sulphuric acid steel Edmeston SX® (UNS S 32615) is a high silicon containing austenitic stainless steel characterised by an excellent corrosion resistance over a wide concentration range at high temperatures, in both static and dynamic conditions. The material has been engineered with a balance of the chemical composition to provide the best possible combination of corrosion resistance (in the region 90-100% sulphuric acid at elevated temperatures), mechanical properties and weldability.

When exposed to sulphuric acid, the material forms a very strong passive surface layer of silicon oxide, protecting against corrosion. The stability of the layer is dependent on a combination of acid concentration and temperature. Under normal operating conditions for a sulphuric acid plant the SX™ material has no detectable corrosion. It has proven results with more than 25 years of operation, including periods of upset conditions.

Figure 1 shows the corrosion resistance of SX® in sulphuric acid. The reference line indicates the iso-corrosion line for 0.1 mm/year (4 mpy).

The corrosion properties of SX™ have been confirmed for dynamic conditions, even for very high acid velocities, as can be encountered in pump impellers etc. Furthermore, the weld exhibits equal or better corrosion properties than the base material.

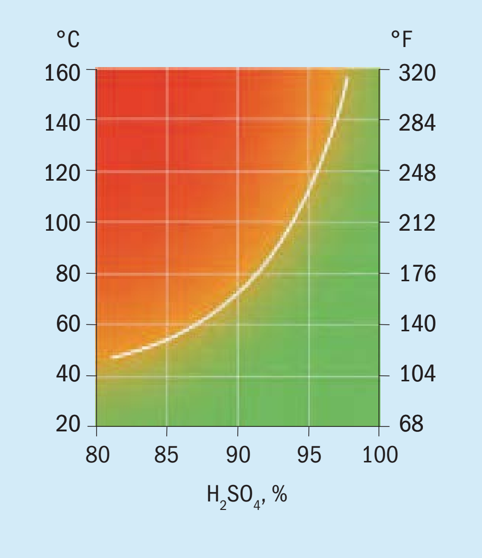
The chemical composition is typically:

Cr	16.5–19.5%
Mo	0.3–1.5%
Ni	19.0–22.0%
Cu	1.5–2.5%
C	0.07%
Si	4.8–6.0%
Mn	2.0%

The limitations that have to be considered are weak oleum or weak acid at elevated temperatures and fluoride content in the acid. A few ppm of fluorides will attack the passive layer in the same way as hydrofluoric acid will etch glass.

The physical and mechanical properties of Outotec Edmeston SX® are similar to those of 316. SX™ is harder, more ductile and has a higher tensile strength. Bending and forming properties are consequently good but require a stronger force. Drilling and machining time is typically increased by 10% compared to the 316-type.

Fig 1: **Outotec Edmeston SX® iso-corrosion diagram 0.1mm/yr**



Welding the SX™ material is accomplished by any welder experienced in the welding of ordinary stainless steel. The calculated welding time should be increased by 10-20% compared to 316, mainly because it should be welded with low heat input which is necessary to keep a low interpass temperature.

The welding properties for silicon containing alloys are mainly dependent on two factors:

- Silicon content. The higher the content, the more difficult to weld. A lower content makes the alloy easier to weld. However, a certain amount of silicon is required to produce the passive film, and hence, protect the material from corrosion.
- Correct composition and quality of weld filler material.

To summarise, the properties of Outotec Edmeston SX® make it a suitable material for all components in the absorption part of a sulphuric acid plant. However, Fig 2: **A few of the many applications of Outotec Edmeston SX®**

Fig 3: **Acid coolers made of Outotec Edmeston SX®**

SX™ equipment has to be designed with a different approach than when using traditional materials. There are sometimes different limitations to consider and advantages to benefit from. Merely transferring a traditional design to alloy equipment is not always a good idea. It is important to possess good knowledge of both material properties and equipment design to avoid problems and to fully benefit from the advantages of the material.

Where is Outotec Edmeston SX® at its best?

A variety of equipment can be made from SX™ material, such as piping, acid coolers, drying and absorption towers, acid distributors, pump tanks, valves, wire mesh and other tower internals.

Some of the many applications of Outotec Edmeston SX® are shown in Fig. 2.

Figure 3 shows SX™ coolers recently installed at a plant where hot water is produced in a closed loop as a means of heat rejection which in turn is cooled by fin-fan coolers.

Despite the range of applications, SX™ material is not being used to its full potential. While SX™ is frequently used for piping, acid distributors, acid coolers, towers, and has been used for decades, virtually no new applications have emerged in recent years. It has become an "ordinary" material for "ordinary" applications.

Fig 4: **The world's largest single train sulphuric acid plants**

Outotec has now taken the performance of the SX™ steel a step forward, extending it's applications to even larger acid plants and for locations with no or scarce water availability.

Enabling maximum capacity at single train acid plants

Outotec has designed and built three acid plants for Ma'aden in Saudi Arabia (Fig. 4). They have been operating at a capacity of 5,000 t/d since successfully passing their performance testing back in 2012. These are the world's largest single train sulphuric acid plants. A multitude of SX™ elements are used at these plants.

Economy of scale will demand even larger single stream capacities in future which are certainly possible.

When considering larger plant units, some restrictions must be observed, which potentially constitute major hurdles, but subject to the design concept, can be overcome.

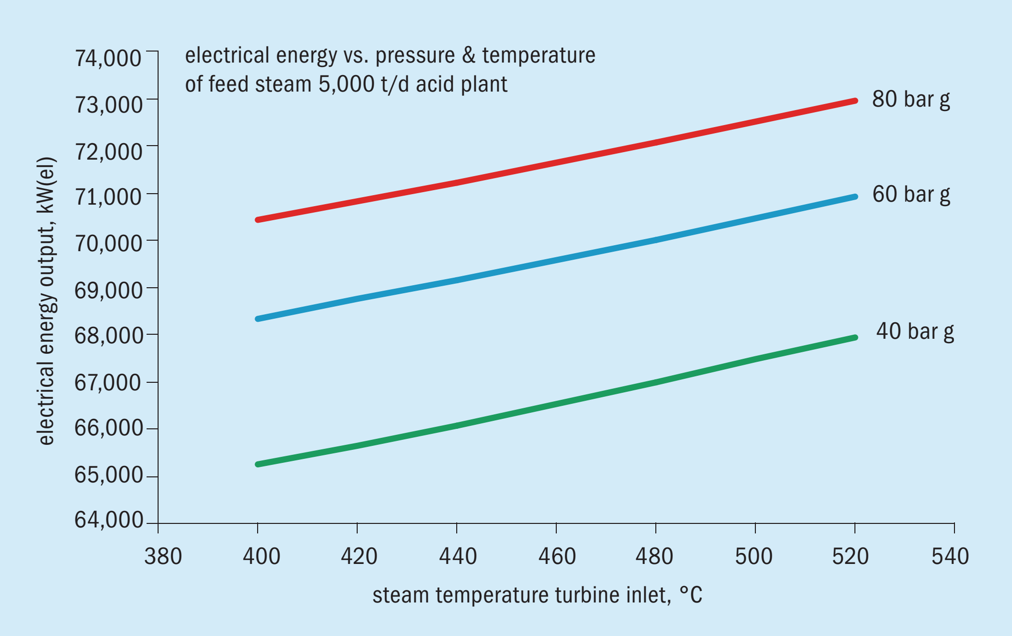
Two parallel main blowers are currently used in large plants. Larger single blowers are available on the market and hence this is not a restriction to design larger capacity acid plants beyond 8,000 t/d.

The waste heat boiler design used by Outotec offers practically unlimited capacity. It is based on a water-tube type boiler (water in the tubes, gas outside), the same principle as applied in power plants. Such boilers can be designed to very large sizes, as opposed to fire tube boilers which are used by other acid plant designers. The large body of the vessel requires extreme wall thickness and becomes unfeasible at larger capacities. In large acid plants, this design requires two parallel vessels, as a single one would not be technically possible. This concept must be excluded for even larger acid plant capacities. Contrary to the fire tube concept, the water tube concept can be applied for practically unlimited acid plant capacities.

To date, the "normal" high pressure steam quality is typically 60 barg; 480°C. However, by increasing the pressure to 80 barg and the temperature to 500°C, it would lead to significantly better thermal efficiency of the turbine-generator, i.e. more electricity output by 3-4%.

This can be easily implemented with water tube boilers, but not with fire tube units. The effect of steam pressure and temperature on the electricity generated is illustrated in Fig.5.

Fig 5: **Electricity generation vs steam pressure and temperature**



While the incremental cost of the boiler for an increase in pressure and temperature is moderate, it is evident that it would enable a remarkable increase in electricity generation.

As the gas throughput of the plant increases with acid output capacity, the vessels, particularly the SO_2 converter, will adequately increase in size. While the impact on the mechanical design of very large vessels can be managed using modern design tools like the finite element method, the uniform distribution of gas to the individual catalyst beds becomes a more challenging issue. Outotec's radial flow converter with integrated heat exchangers is perfectly suitable for such enlargement in capacity. In Fig. 6, a sketch of a modern 5-bed converter is presented and the radial gas distribution from the centre to each bed is demonstrated.

The figure also shows a typical outcome of the CFD modelling which is performed as standard for all larger acid plants. This tool enables the quality of the velocity and temperature distribution to be improved even further.

Contrary to this design, the alternative conventional converter with lateral gas entry will not be able to achieve the same uniformity. Uniformity is important not only for the function of the unit, but also to minimise SO_2 stack emissions. Not even the slightest bypass flow, channelling or maldistribution can be tolerated as it will have an immediate impact on the emissions.

Large absorption towers of conventional design have been built up to 12 m diameter, which would theoretically be suitable for acid plant capacities of up to say 6,000 t/d. However, here also the issue of uniform gas and liquid distribution becomes paramount.

While a variety of liquid distributor designs are available and well proven, the gas distribution has been widely disregarded as a critical issue in the past and was overcome by conservatively designed tower packing. CFD simulations have shown that larger towers with high efficiency internals cannot tolerate the conventional single lateral gas inlet, even when this is split into two nozzles.

Since the 1970s, Outotec has built a

Fig 6: **Radial flow converter and CFD modelling**

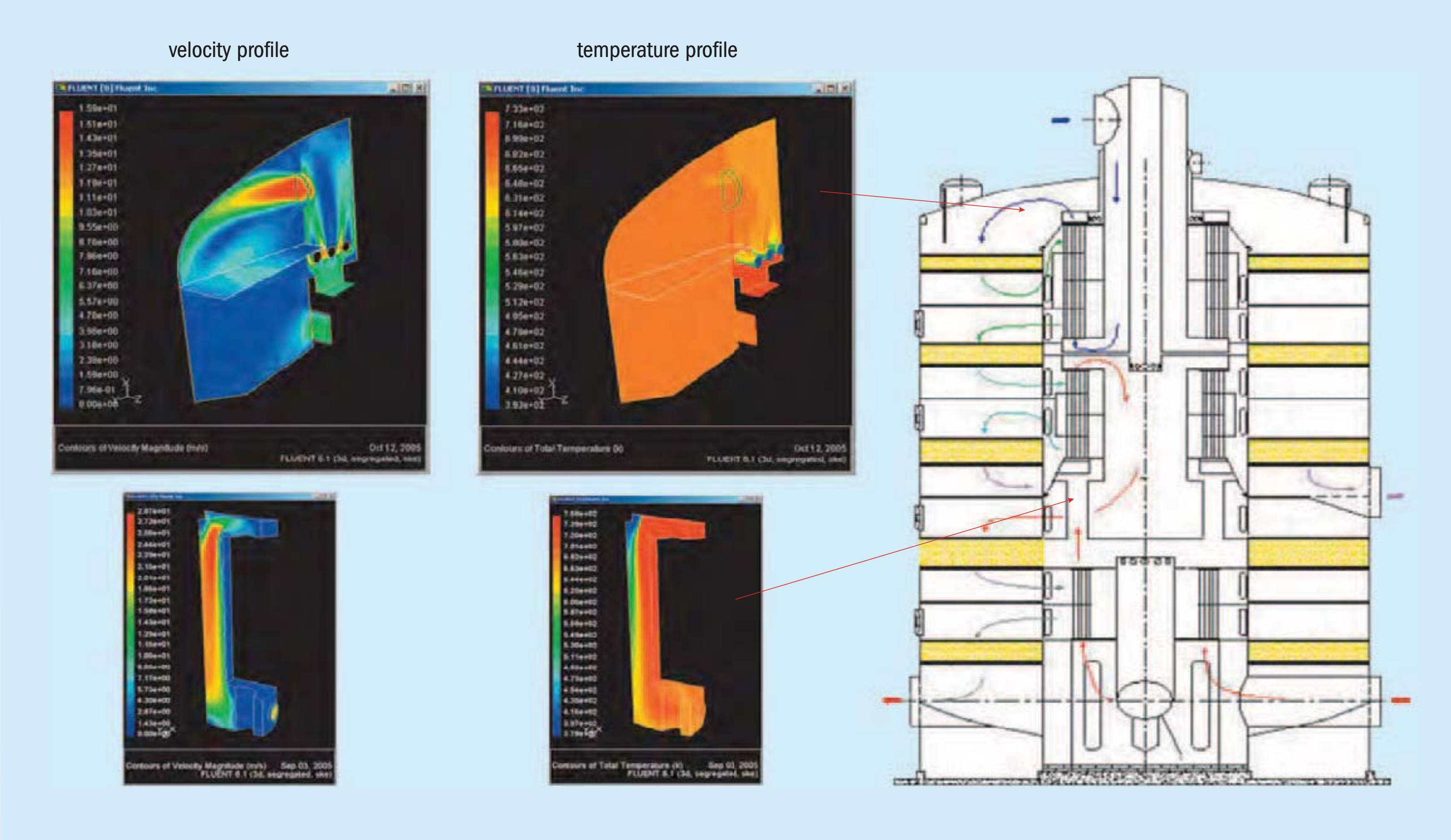


Fig 7: **Conventional vs radial flow absorber**

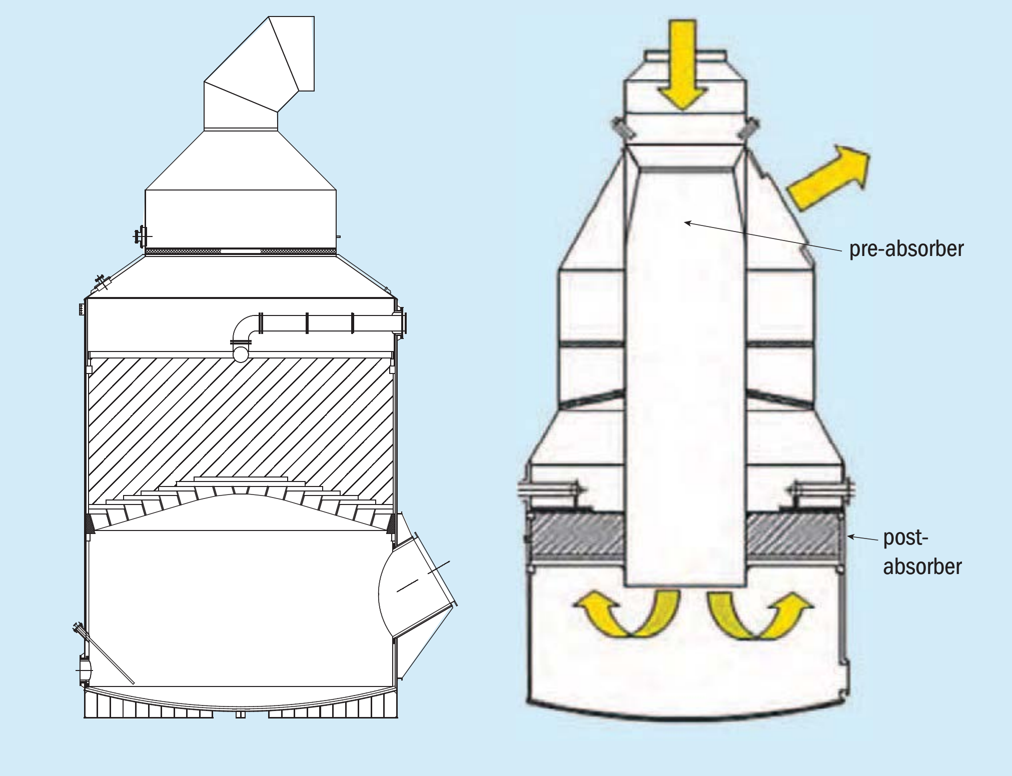


Fig 8: **Outotec LURO burner**

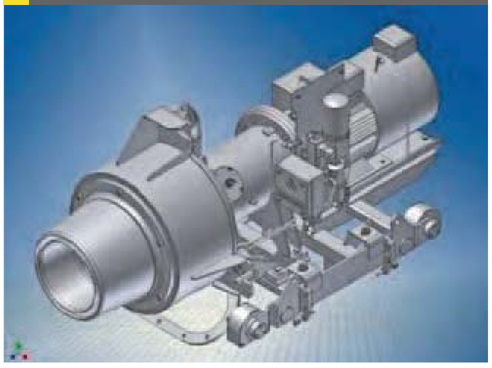
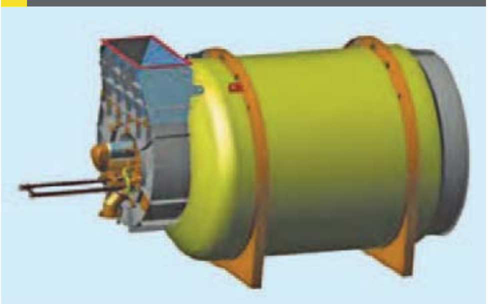


Fig 9: **Outotec sulphur combustion furnace**



number of proprietary radial flow towers for both drying towers and absorbers using the same principle as applied for the converter, namely radial and uniform gas distribution (Fig. 7). Alloy towers as well as brick-lined towers have been designed and built and are in operation in metallurgical and sulphur burning plants.

SX™ is the material of choice for such towers. The sensitivity of all Si-alloyed stainless steels to SO_3/oleum is well known and conventional towers must be very carefully designed to avoid local oleum formation, particular at the tower walls at the presence of high SO_3 concentration in the incoming gas. The venturi type pre-absorber does not exhibit such restrictions, nor does the downstream packed bed post-absorber as they are fed centrally by the gas, rather than laterally as in the conventional design.

Radial flow absorbers are effectively two serial absorption steps, consisting of an internal venturi type absorber plus a small packed bed section downstream. A major advantage is the omission of large openings at the lower tower shell (otherwise required as gas inlet) and the related mechanical design weakness at this area. Such towers would be suitable for plant capacities well beyond 8,000 t/d.

A multitude of sulphur spray nozzles with an extremely large combustion furnace is required for a conventional large acid plant. Not only is a variation in plant load difficult to control, but also further enlarged furnaces would present a serious mechanical design problem. With ever larger furnaces, the integrity of the refractory brick lining diminishes and hence the stability of such a furnace is questionable.

Fig 10: **Outotec proprietary SX® butterfly valve**

Outotec uses a special sulphur burner Outotec LURO (Fig. 8), which generates extremely fine atomised sulphur droplets and hence requires much smaller furnaces (Fig. 9) compared to spray nozzles (~25% of the furnace size). Only two burners are required for a 5,000 t/d plant, while the number of spray nozzles would be around 10. The Outotec LURO technology can be used between 20 and 100% load without the need to change parameters, while in the case of nozzles, some nozzles must be shut off at reduced load. This not only exposes the unused nozzles to the hot furnace, but they are also frequently subject to steam (cooling medium) leakages into the furnace with all the downstream corrosion effects.

Outotec's design for extremely large plants, say beyond 6,000 t/d, would have two furnaces attached to the water tube boiler in the "boxer" arrangement and thus offer virtually unlimited capacity.

Sulphur is finely atomised at a rotating cup, which is cooled by primary combustion air. No cooling steam is applied and hence no leakage of water into the process gas can occur.

Acid plants require adequate flows of acid circulating at the individual towers. The flows are virtually proportional to the plant capacity and thus demand large acid piping for large plants. Using multiple parallel acid pumps, piping of SX™ can be made for any size and diameter. However, very large butterfly valves suitable for control purposes are not available on the market off the shelf. Outotec has designed and used its proprietary SX™ butterfly valves (Fig. 10), which are currently available up to DN800 and can be expanded to any larger size if required.

Based on these examples, Outotec strongly believes that the current largest units with 5,000 t/d capacity do not constitute a limit for future single stream acid plant capacities.

The proper use of SX™ material potentially makes possible large single stream acid plant capacities, well beyond the current state of the art.

When water is scarce

Sulphuric acid plants require the rejection of large quantities of waste heat from the acid section, – about 500,000 kcal/t of acid produced, even though this can be minimised by the use of heat recovery systems. Usually cooling water is used for this purpose. The most common systems are equipped with a closed cooling loop with an evaporative open water cooling tower, requiring fresh water make-up of reasonably good quality to avoid scaling and fouling of the coolers.

The water must be conditioned with suitable chemicals, which can be difficult to recycle as they end up in the blow-down drain of the cooling tower. So, when water is available at a premium or not at all, this technology is not an option.

Seawater has been used in many plants for cooling purposes on a once-through basis. While this offers economical advantages (less capital cost), it requires higher alloy materials for acid coolers due to increased corrosion potential on the water side. Subject to temperature, this water also requires conditioning with chemicals in order to avoid scaling and biological fouling, e.g. by algae. The return water is usually limited in temperature and must be carefully supervised to avoid contamination of the seawater habitat. The application is obviously limited to plants that are located close to the sea.

For acid plants that are constructed at remote areas with little or no availability of water, or where the use of water is restricted by environmental legislation, other ways of heat rejection must be employed, such as air cooling by fin-fan coolers. This was and is also quite common in urban areas. Early installations used 316L material with low acid temperatures <75°C, low fluid velocities and hence very large and expensive coolers. The acid was pumped directly to the finned tube coolers. Some applications used anodic protection to allow higher acid temperatures, although this has been found not to be a reliable method.

Fig 11: **Fin-fan closed loop water coolers**

Fig 12: **Direct acid fin-fan coolers**

The current state-of-the-art acid plant is characterised by a closed loop of demineralised water that is heated up to typically 80-90°C, and then fed to fin-fan coolers made of ordinary material (Fig. 11). After being cooled down to 50-60°C, the water is then recycled back to the acid plant.

While the fin-fan air coolers are conventional and operate with hot water only, the acid coolers, mostly shell and tube type, are subject to much higher material surface temperatures (as compared to cold cooling water), and hence impose more severe conditions with respect to corrosion resistance. Anodically protected coolers made of 304/316 type material will inherently suffer larger corrosion rates and must operate in co-current flows in order to keep the material surface temperatures at approximately the same at both ends.

At high material temperatures, those coolers demand the control within a range of protection which is increasingly diminishing or even non-existent at temperatures beyond 100°C. Coping with plant load variations, and hence temperature level fluctuations, makes a continuous passivation of the material even more difficult. Therefore, this is another device that may fail and interfere with operation.

For the purpose of hot water production, shell-and-tube acid coolers made of SX™ have been available for a decade with excellent performance and virtually zero corrosion.

Although the shell-and-tube acid coolers are proven technology, there have been cases where acid leaks have occurred for various reasons, which can lead to disastrous corrosion. The intermediate closed water loop must thus be continuously monitored to avoid uncontrolled flow of acid or water in case of such leakages. One must ensure that the acid pressure is always higher than the water pressure in order to enable early detection of a leak on the water side. Clean, demineralised water should be used for the closed loop, and on-line conductivity meters will provide fast and reliable information.

To avoid the risk of leakages with subsequent water contact, formation of diluted acid and heavy corrosion, Outotec has developed direct fin-fan acid coolers made of SX™ steel (Fig. 12).

All piping, headers and finned tube banks are made of SX™ with fins of suitable material to be able to be subjected to any environmental condition. As SX™ does not restrict flow velocities and acid temperatures below 140°C, the coolers can be designed efficiently and economically and the overall installed cost can be lower than the closed water loop alternative. The operating cost is also lower as the intermediate water pumping is omitted.

The absence of water, which is the acid plant's greatest enemy, completely eliminates the risk of diluted acid formation.

In recent years the number of events in acid plants has risen significantly where acid leakages with subsequent diluted acid corrosion, hydrogen formation and eventually hydrogen explosion were involved. It appears that this topic is of increasing concern in the industry with regard to both health and safety of personnel, as well as damage to equipment and plant outages. Fortunately, no fatalities have been reported from those events yet.

The application of direct fin-fan air coolers made of SX™ steel completely eliminates such risk and beside the economic advantages, contributes substantially to reliable and safe plant operation. ■

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8 54
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11 57
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14 60
15 61
16 62
17 63
18 64
19 65
20 66
21 67
22 68
23 69
24 70
25 71
26 72
27 73
28 74
29 75
30 76
31 77
32 78
33 79
34 80
35 81
36 82
37 83
38 84
39
40
41
42
43
44
45
46

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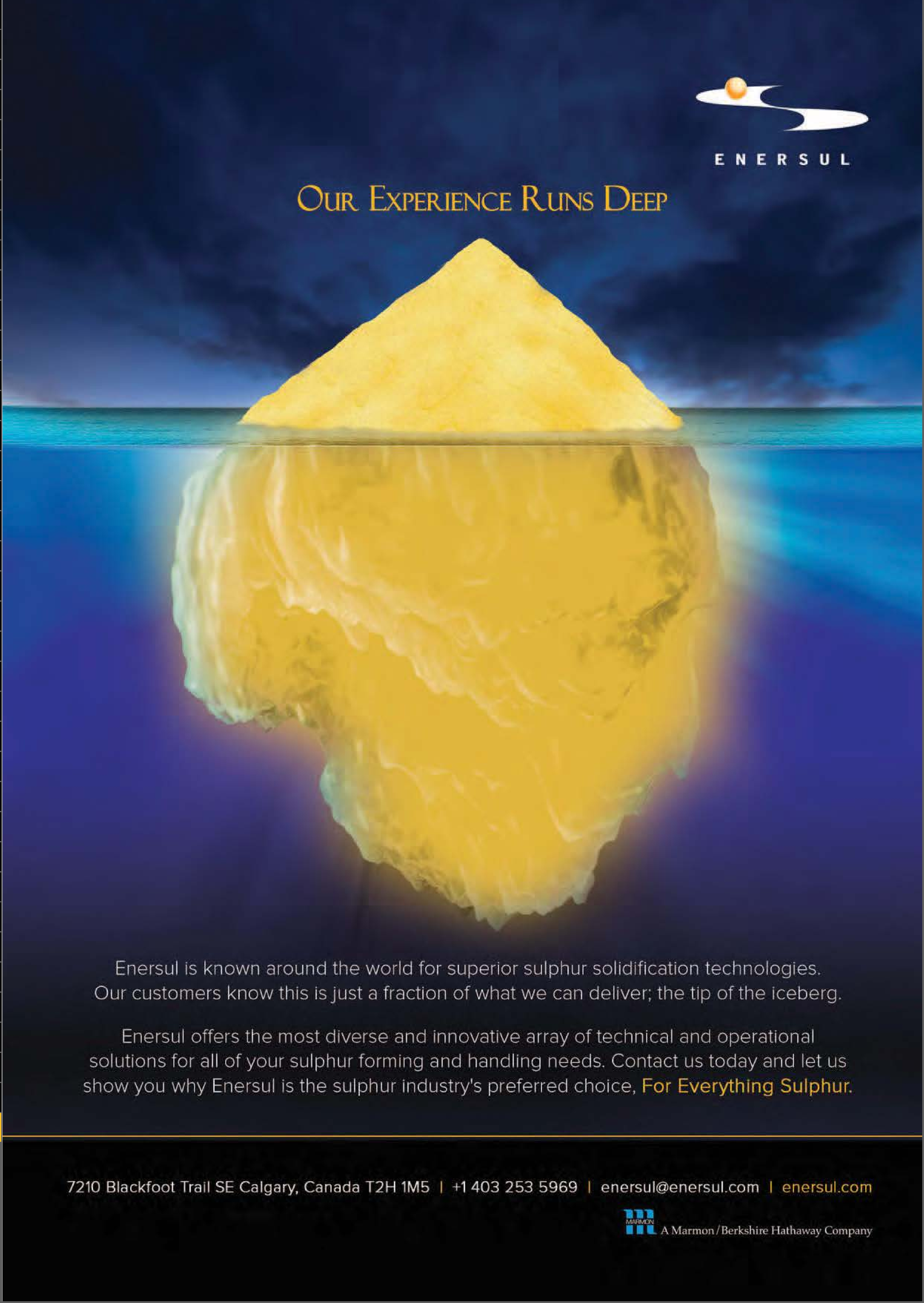
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