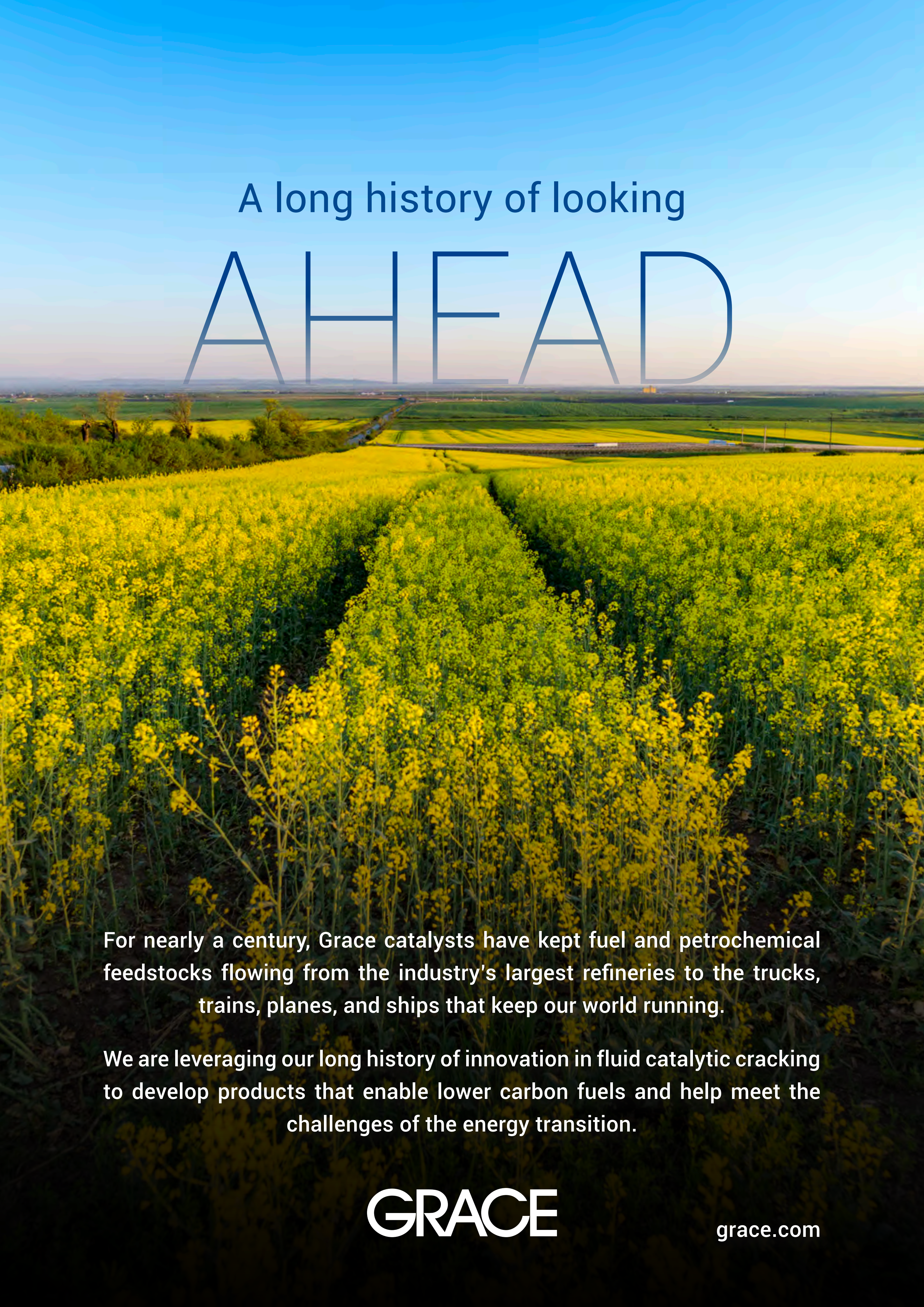
HYDROCARBON ENGINEERING

July 2023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CONTENTS

July 2023 Volume 28 Number 07 ISSN 1468-9340

THIS MONTH'S FRONT COVER

Ethylene is the most important intermediate in the petrochemical value chain, and its production is uniquely sensitive to thermal insulation performance. Aspen Aerogels' article on p. 16 covers the root causes of degradation for both hot and cold insulation, diagnostic indicators to look for, and ways to improve thermal performance in ethylene service.

UNION TECH

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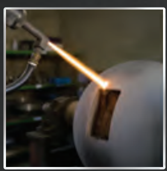


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COMMENT

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HYDROCARBON ENGINEERING

CALLUM O'REILLY
SENIOR EDITOR

Over the past year, it has been easy to lose focus of the global nature of the energy crisis. Much of the attention has been on Europe, which is understandable given the fact that the continent has had to quickly adapt to life without Russian energy. However, as highlighted by the International Energy Agency (IEA) last year, this is truly a global energy crisis, and major impacts are being felt in many emerging and developing economies. The IEA points to the number of people worldwide who lack access to electricity, the large majority of whom live in Sub-Saharan Africa.

In its 'Africa Energy Outlook 2022' report, the IEA notes that the increased cost of energy, food and other commodities, as a result of the war in Ukraine, has affected many parts of Africa's energy systems, including reversing positive pre-COVID-19 trends in improving access to modern energy.[1] The continent is also facing more severe effects from climate change than most parts of the world, despite accounting for less than 3% of the world's energy-related carbon dioxide (CO_2) emissions to date.

In this issue of *Hydrocarbon Engineering*, our regional report focuses on the current status of the oil and gas sector in Sub-Saharan Africa. Contributing Editor, Gordon Cope, provides a breakdown of the latest developments in several countries, and examines a number of factors that are limiting prosperity in the region.

However, as Cope explains, opportunities do beckon, and green shoots are appearing across several countries. The IEA's 'Africa Energy Outlook' aims to set out a path to bring modern energy access to all Africans by the end of this decade. As Fatih Birol, the IEA's Executive Director, explains: "The new global energy economy that is emerging offers a more hopeful future for Africa."

Although renewables will be the driving force for Africa's energy sector this decade – with solar leading the way – the IEA notes that the continent's industrialisation will rely in part on expanding natural gas use. Africa has more than 5000 billion m^3 of natural gas resources that have not yet been approved for development, with the potential to provide an additional 90 billion m^3/yr by 2030. Cumulative CO_2 emissions from the use of these gas resources would bring Africa's share of global emissions to just 3.5%.

Africa is also set to be at the heart of the hydrogen revolution. A recent study from the European Investment Bank (EIB), International Solar Alliance and the African Union has set out the continent's "extraordinary green hydrogen potential." The report considers investment opportunities in four African hubs: Mauritania, Morocco, southern Africa and Egypt. The analysis suggests that harnessing Africa's solar energy to produce 50 million tpy of green hydrogen by 2035 could help to secure global energy supply, create jobs, decarbonise heavy industry, enhance global competitiveness, and transform access to clean water and sustainable energy.[2]

On the topic of hydrogen, I'm pleased to announce that the Summer issue of our sister publication, *Global Hydrogen Review*, is out now. For detailed analysis of green (and blue) hydrogen production, and much more, please sign up for a free subscription to the magazine (turn to p. 22 for more details).

1. 'Africa Energy Outlook 2022', International Energy Agency (IEA), (June 2022).
2. 'New study confirms €1 trillion Africa's extraordinary green hydrogen potential', European Investment Bank (EIB), (21 December 2022).

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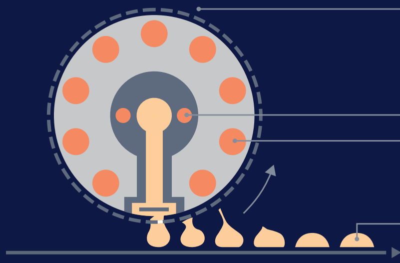

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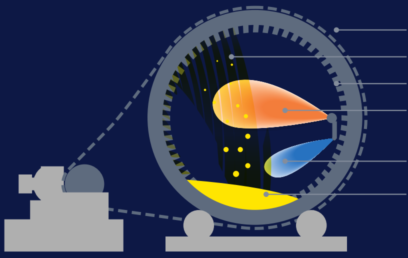

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Europe | Lummus Technology and MOL Group team up on advanced waste plastic recycling

Lummus Technology and MOL Group have announced an agreement to cooperate in the deployment and integration of chemical recycling of plastics at MOL's assets in Hungary and Slovakia. Chemical recycling of plastics is part of MOL's commitment to collect close to 5 million t of municipal solid waste, which includes the treatment and related investments.

MOL has committed to drive circularity and has recently invested in addressing waste plastics recycling in Central Europe.

Lummus' Green Circle business unit will provide its advanced waste plastic pyrolysis technology to MOL, which effectively converts plastic waste into high-value chemicals and feedstocks, creating circularity. Lummus will also provide its experience and expertise in steam cracking, catalytic cracking and residue processing technology to ensure that integration with MOL's existing assets is optimised.

France | EDF, Holcim, IFPEN and Axens to support new project

Holcim, IFPEN, Axens and EDF have signed a Memorandum of Understanding (MoU) to develop 'Take Kair' – an industrial e-kerosene pilot project in Pays de la Loire, France, that will meet the needs of the French e-SAF industry. The main offtaker of the e-kerosene produced by this facility would be Air France-KLM.

The cooperation will contribute to the development of the French SAF production industry – a priority raised by the French President during his speech on 16 June 2023 – and the production of e-kerosene will contribute to the decarbonisation of air transport. It is envisaged that Take Kair will avoid the emission of more than 1 million tpy of carbon dioxide (CO_2).

The project's success relies on the partners' commitment and expertise.

Worldwide | LNG trade on the up

In 2022, global trade in LNG increased by 2.6 billion ft^3/d, or 5% compared with 2021, and averaged 51.7 billion ft^3, according to data from CEDIGAZ.

Growth in global LNG trade was supported by liquefaction capacity additions, primarily in the US, and increased LNG demand in Europe as LNG continued to displace pipeline natural gas imports from Russia.

Similar to previous years, LNG exports in 2022 increased the most from the US, growing by 1.4 billion ft^3/d (16%) compared with 2021. In 1H22, the US became the world's largest LNG exporter for the first time, after the new Calcasieu Pass LNG export facility was commissioned. However, because of the shutdown of the Freeport LNG export terminal, US LNG exports declined in the second half of the year. In 2022, Qatar and Australia remained the top two global LNG exporters.

Among LNG-importing regions, Europe (including Turkey) posted the largest increase in LNG imports globally, increasing by 65% (6.5 billion ft^3/d) compared with 2021.

Finland | Neste to invest in a liquefied waste plastic upgrading unit

Neste has made the final investment decision (FID) to commence construction of upgrading facilities for liquefied plastic waste at its Porvoo refinery in Finland.

With an investment of €111 million, Neste will build the capacity to upgrade 150 000 tpy of liquefied waste plastic.

Upgrading is one of the three processing steps turning liquefied waste plastic into high-quality feedstock for new plastics: pretreatment, upgrading and refining.

The investment is part of a broader project (PULSE), which has received an EU Innovation Fund grant of €135 million if fully implemented, and is targeting a total capacity of 400 000 tpy.

Pretreatment and upgrading of liquefied waste plastic play an important role in Neste's approach to chemical recycling.

The project will see Neste building new assets at the Porvoo refinery, as well as leveraging existing assets through retrofitting, to scale up chemical recycling quickly and efficiently. The upgraded liquefied waste plastic will then be processed in the conventional refinery, in which it will replace a portion of the fossil resources processed at the Porvoo refinery.

Preparation works were successfully completed during 1H23.

WORLD NEWS

DIARY DATES

05 - 08 September 2023
Gastech
Singapore
www.gastechevent.com

17 - 20 September 2023
GPA Midstream Convention
San Antonio, Texas, USA
www.gpamidstreamconvention.org

17 - 21 September 2023
World Petroleum Congress
Calgary, Alberta, Canada
www.24wpc.com

26 - 28 September 2023
Turbomachinery & Pump Symposia
Houston, Texas, USA
tps.tamu.edu

02 - 05 October 2023
ADIPEC
Abu Dhabi, UAE
www.adipec.com

03 - 05 October 2023
AFPM Summit
Grapevine, Texas, USA
summit.afpm.org

09 - 12 October 2023
2023 API Storage Tank Conference & Expo
Denver, Colorado, USA
events.api.org/2023-api-storage-tank-conference-expo

06 - 08 November 2023
Sulphur + Sulphuric Acid 2023
New Orleans, Louisiana, USA
www.sulphurconference.com

13 - 16 November 2023
ERTC
Lake Maggiore, Italy
worldrefiningassociation.com/event-events/ertc

05 - 07 December 2023
16th Annual National Aboveground Storage Tank Conference & Trade Show
The Woodlands, Texas, US
www.nistm.org

10 - 14 June 2024
ACHEMA 2024
Frankfurt, Germany
www.achema.de/en

China | Linde signs contracts with Wanhua Chemical Group

Linde has signed a series of contracts with Wanhua Chemical Group, expanding the companies' cooperation across multiple key sites in China.

In Fujian province, Linde will acquire three air separation units (ASUs) from Wanhua, including two ASUs that are currently under construction and expected to start up in 2024 and 2025, respectively. Linde will enter into long-term agreements with Wanhua for the supply of industrial gases to its chemical production sites through the acquired ASUs. These plants will further enhance Linde's network density in Fujian province, and foster future growth.

Linde has also extended its long-term industrial gas supply agreements with Wanhua in Ningbo and Yantai, including investment in decarbonisation to reduce carbon dioxide equivalent (CO_2e) emissions by approximately 500 000 tpy.

Saudi Arabia | Aramco and TotalEnergies award contracts for petrochemical facility expansion

Aramco and TotalEnergies have awarded engineering, procurement and construction (EPC) contracts for the US$11 billion Amiral complex – a future world-scale petrochemicals facility expansion at the SATORP refinery in Saudi Arabia.

The award of these contracts for the main process units and associated utilities marks the start of construction work on this joint project, following a final investment decision (FID) in December 2022. Integrated with the existing SATORP refinery in Jubail, the new petrochemical complex will house one of the largest mixed-load steam crackers in the Gulf, with the capacity to produce 1.65 million tpy of ethylene and other industrial gases.

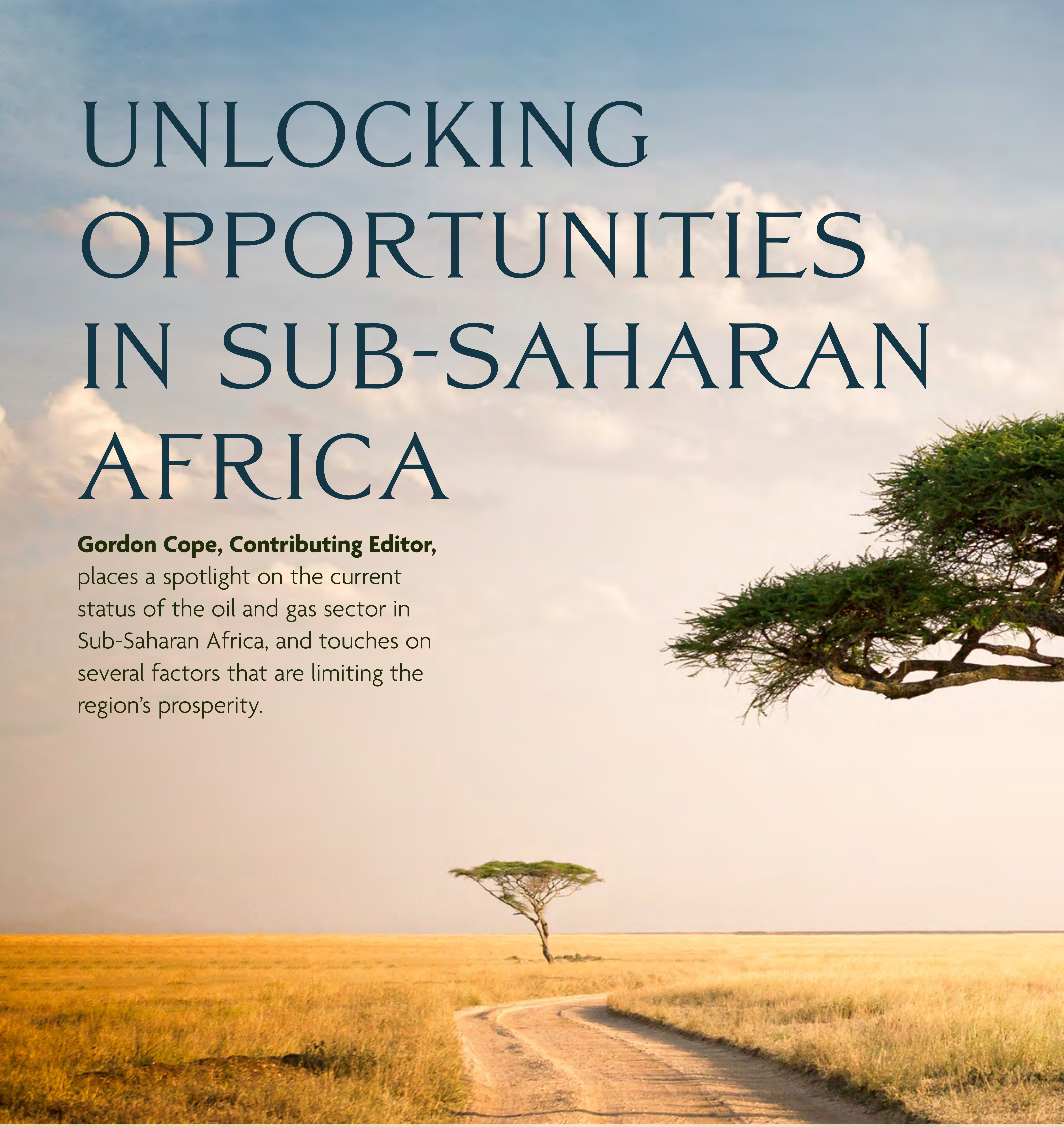
This expansion is expected to attract more than US$4 billion in additional investment, across a variety of industrial sectors.

China | BASF breaks ground on polyethylene plant

BASF has announced that it has broken ground on a polyethylene plant at its Verbund site in Zhanjiang, China. The new plant, with the capacity to produce 500 000 tpy of polyethylene, will serve the fast-growing demand in China. The plant is scheduled to start up in 2025.

"China's demand for polyethylene has experienced rapid growth and is going to outpace the rest of the world," said Bir Darbar Mehta, Senior Vice President of Petrochemicals Asia Pacific at BASF. "With the groundbreaking ceremony, BASF will enter the polyethylene market in China via a competitive production footprint in its fully integrated production site in Zhanjiang, catering to our customers in the consumer goods, packaging, construction and transportation industries."

UNLOCKING OPPORTUNITIES IN SUB-SAHARAN AFRICA



Gordon Cope, Contributing Editor, places a spotlight on the current status of the oil and gas sector in Sub-Saharan Africa, and touches on several factors that are limiting the region's prosperity.

Sub-Saharan Africa is in a bind when it comes to fuel. Since 2020, a wave of refinery closures in Zambia, South Africa and Cameroon related to COVID-19 dramatically reduced the region's ability to supply an estimated 2 million bpd of diesel, gasoline and jet fuel. Since then, complications surrounding the Ukraine war have impacted cost, as well as the ability to import fuels, including 700 000 bpd of diesel.

However, Sub-Saharan Africa is also home to prolific natural resources. Over 140 million years ago, when the ancient supercontinent of Gondwana separated, Africa and South America split along the mid-Atlantic ridge. In South America, exploration of the sedimentary and stratigraphic structures that were created in Guyana's offshore basins has led to a new major oil exporter.

Many of these geological features are mirrored on Africa's Atlantic coast. On paper, the region represents immense opportunities, but many jurisdictions are plagued by civil unrest, corruption and mismanagement that deter investment. Still, progress is being made.

Nigeria

The imminent commissioning of Nigeria's greenfield Dangote refinery appears to be a beacon in the gloom.

Construction of the US$20 billion facility (and at 650 000 bpd, it is the largest single train refinery in the world), has been completed. When it comes onstream, it is expected to displace 300 000 bpd of costly gasoline imports, and generate export opportunities to international markets.

There is some concern as to when it will reach full production, however. While preliminary testing has already begun, the plant is not expected to reach full capacity until 2024.

A significant change in the country's output is also adding a new wrinkle with regards to reliable feedstock supplies. Crude production has dropped from 2 million bpd when the project was conceived a decade ago, to slightly over 1.3 million bpd today.

Part of plunging production is due to larceny; the theft of crude from pipelines remains a significant problem. In October 2022, Nigerian authorities uncovered a bootleg crude pipeline network in the fractious Niger Delta region that was being used to siphon off crude. The 4 km line diverted oil to the Atlantic Ocean, where it was loaded onto barges and vessels. It was part of the US$3.3 billion worth of petroleum products that are stolen annually, but its demise is not expected to significantly impact illegal losses.

The Dangote Group is also building a US$2 billion petrochemical plant adjacent to its refinery. The new facility, the only major petrochemical project currently underway in the Sub-Saharan, is designed to produce 900 000 tpy of polypropylene to cater to the plastics industry in Africa and abroad. It will rely on gas from the Niger Delta region for feedstock.

In April 2023, NNPC signed a contract with Norway's Golar LNG to build a new floating LNG facility (FLNG). The announcement did not provide specific details, but Golar has a similar contract with BP to supply a 2.45 million tpy FLNG for the Greater Tortue Ahmeyim field in Mauritania. Nigeria, which has over 200 trillion ft^3 of gas reserves, exports more than 16 million tpy of LNG – primarily to European markets.

Mozambique

Mozambique possesses significant gas reserves in its offshore waters in the Indian Ocean. In late 2022, Eni's Coral Sul FLNG plant, located in northeastern Mozambique near the border of Tanzania, celebrated its first shipment. The 3.4 million tpy plant, under construction since 2019, uses 450 million ft^3/d of gas derived from the ultra-deep Coral reservoir. Unfortunately, the region is engulfed in a violent Islamist insurgency, creating security and social problems that have complicated the development of two other projects: ExxonMobil's Rovuma plant and TotalEnergies' Mozambique LNG.

Tanzania

Tanzania has similar geological prospects to Mozambique. Shell has discovered an estimated 16 trillion ft^3 of offshore gas, and Equinor up to 20 trillion ft^3. The two companies have proposed the US$30 billion Tanzania LNG project, with the potential to produce up to 10 million tpy. In March 2023, Equinor and Shell completed talks with the Tanzanian government and signed a deal to formally develop the project. The agreement calls for an FID by 2025, with construction taking up to six years afterwards in the Port of Lindi, located in southeast Tanzania near the border of Mozambique.

Ghana

Ghana, located in the Gulf of Guinea, has over 600 million bbl of crude reserves, and produces approximately 175 000 bpd. Its capital, Accra, is home to 2.6 million citizens, but is serviced by only one refinery, Sentuo Petrochemical's 45 000 bpd Tema plant. In 2021, the company began construction of a 40 000 bpd expansion, with further phases planned to increase production by an additional 60 000 bpd. Total cost of the expansions is estimated at US$3 billion.

Senegal

Recent offshore exploration in Senegal, located on the west coast of Africa, has uncovered over 1 billion bbl of crude and 40 trillion ft^3 of gas. The Sangomar field is operated by Woodside Energy. The Australian firm commissioned a floating production, storage and offloading (FPSO) ship, which is expected to come onstream in late 2023. The initial phase will produce 100 000 bpd; further phases will integrate other oilfields as well as gas production.

In light of exploration developments, Senegal's SAR refinery underwent a recent renovation, increasing capacity to 1.2 million tpy. Its owner, Petrosen, and partners have plans to boost production to 2.5 million tpy. The latter target is significantly above domestic demand of 1.6 million tpy, opening up opportunities to export fuels to adjacent countries.

Gabon

Located in the Gulf of Guinea, Gabon has been producing crude for several decades, but output has declined from over 350 000 bpd in the late 1990s to around 200 000 bpd. Crude exports are the major foreign currency earner in the country, and since 2019, the government has enacted enticing royalty laws and introduced licensing rounds to attract more exploration for the estimated 2 billion bbl of undiscovered resources offshore. Gabon has one refinery, the ageing 24 000 bpd Sogara plant located in Port Gentil. It is currently adding a hydrocracker in order to produce ultra-low-sulfur diesel fuel. Construction is expected to be completed by 2025.

South Africa

South Africa's downstream sector is facing a series of challenges. Prior to COVID-19, the country had six refineries with a total capacity of over 700 000 bpd. Since then, 80% of that capacity has been lost to unplanned shutdowns and closures. Currently, only two plants are still operational.

In 2022, the federal government established guidelines on petroleum products specifications, compatible with European standards, with a 2027 implementation deadline. The midstream sector bemoaned the government's reticence to offer financial support for the changes; BP and Shell's Sapref refinery, the largest in South Africa, subsequently closed, citing shareholder reluctance to make upgrading investments.

One of the plants still in operation, Sasol and Total's Natref refinery, is still weighing up its options. According to the operators, it would cost over US$50 million to meet the clean fuel standards. It is also investigating a green hybrid refinery concept, in which biofeedstock would be used to reduce greenhouse gas (GHG) emissions.

Sasol's 160 000 bpd synthetic fuel plant, Secunda, is also undergoing transformation. Under apartheid-related sanctions, Sasol devised methods to create fuels from the coal gasification method, in which pulverised coal is treated with oxygen and steam under high heat conditions to produce 'coal gas', a mixture of carbon monoxide, hydrogen and methane, which can then be converted into liquid fuels. The process is energy-intensive, and the plant is considered the world's largest GHG emitter, producing approximately 56 million tpy of emissions. Air Liquide, who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took over the 40 000 tpy oxygen plant onsite, has announced plans to procure 900 MW of renewable energy from TotalEnergies, who is building solar plants and wind farms in the Northern Cape province. The output will be shipped via high-voltage transmission lines to the Secunda site. Air Liquide estimates that when the project comes online in 2025, it will reduce onsite emissions by over 30%.

Angola

Angola, once the catchword for strife in Africa, is making significant strides. Although the era of 2 million bpd production has fallen to slightly over 1 million bpd, a protracted civil war was settled and relations have improved between neighbours.

State-owned Sonangol operates the only refinery in Angola – the 65 000 bpd Luanda complex. It recently announced a joint venture (JV) with Italy's Eni to increase gasoline capacity from 280 tpd to 1100 tpd. It also has a JV with London-based Gemcorp to develop the 60 000 bpd Cabinda refinery, at a cost of US$920 million.

The Angolan Ministry of Petroleum awarded a contract to US-based Quanten Consortium to build the Soyo refinery, a 100 000 bpd plant costing US$3.5 billion. The government has also pursued investors to build a 200 000 bpd refinery in Lobito, at an estimated cost of US$8 billion.

When completed, the additions will theoretically meet the country's domestic needs of 440 000 bpd. Angola also has an ambitious plan to displace fuel supplies from the Middle East. In 2022, Sonangol revitalised a project to build a fuel pipeline to landlocked Zambia. The line, which is estimated to cost US$5 billion, would stretch over 2000 km from the Angolan coast to a storage hub near the urban region of Lusaka. From there, branch lines could be extended to the seven other countries that border Zambia. The region would benefit from regional proximity and commercial advantages.

Namibia

Namibia, located north of South Africa on the Atlantic coast, has no domestic refining capacity, but is seeing significant growth in its upstream oil and gas sector. In 2022, Shell, Total and QatarEnergy discovered the Venus and Graff 1 fields, containing an estimated total of 1 billion bbl of crude. Shell also recently announced a third discovery at its Jonker-1X well. Although crude production is several years in the future, the country is set to produce natural gas from its 600 billion ft^3 Kudu gas field in 2024. Namibia is also pursuing an ambitious plan to become a green energy hub, leveraging off its abundant sun, wind and rare earth metals with a proposed US$1 billion investment fund to kickstart hydrogen, green ammonia and jet fuel production.

Kenya

In 2013, Kenya's only refinery, KPRL, located in the Port of Mombasa, was shut down. Since then, numerous attempts have been undertaken to revive the 71 000 bpd facility, to no avail. In 2022, Kenya Pipeline Co. (KPC) took over the defunct plant in order to use its 500 million l storage tanks to streamline imports. The government is currently in preliminary discussions with Italy's Eni to convert part of the facility for biofuels production.

In light of geological surveys that speculated that as much as 4.5 billion bbl of oil might rest in Kenya's offshore section of the Indian Ocean, the government had been contemplating a 120 000 bpd refinery in the Port of Lamu. The plan was dashed with cold water, however, when an exploratory well drilled by Eni in 2022 came up empty.

Uganda

Landlocked Uganda has approximately 1.4 billion bbl of recoverable oil located in the complex graben structures that bisect the country. For over a decade, negotiations to build a domestic refinery have been underway. In 2018, AGRC, a JV between General Electric and Italy's Saipem, reached an agreement with the government to promote the 60 000 bpd Uganda Oil refinery in the western region of Uganda. In late 2022, the plan advanced by one step with the announcement of a front end engineering and design (FEED) study on the US$4.5 billion project. The plant is expected to use feedstock from the 560 million bbl Kingfisher oilfield, which operator CNOOC expects will produce approximately 40 000 bpd. TotalEnergies' Tilenga oilfield is eventually expected to add an additional 190 000 bpd.

Problems

Lately, Sub-Saharan nations that seek to lift prosperity through the development of oil and gas have found themselves in the crosshairs of environmental, social and governance (ESG) guidelines. Shell and TotalEnergies have announced plans to divest from Nigeria, citing ESG principles that make their energy assets in the contentious Niger Delta region incompatible with net zero goals. Analysts estimate that recent international oil company (IOC) divestments in the country exceed US$20 billion, and upstream exploration expenditures have dropped from US$27 billion in 2014 to US$6 billion in 2022. While independents and national oil companies (NOCs) can fill some of the void, losing the leading Western companies that essentially developed Africa's oil and gas sector is a significant impediment to raising capital and finding experienced partners to develop expensive, technically-challenging offshore assets.

The future

Renewable resources and the potential for the new hydrogen economy beckons, and green shoots have been appearing in South Africa, Namibia and other jurisdictions. But the immense infrastructure investments needed to achieve economies of scale are unlikely to emerge within the continent that is currently significantly underserved by conventional refining and petrochemical infrastructure. Potential investors place a high-risk factor on many jurisdictions and are constrained by ESG considerations. Sub-Saharan countries seeking to advance the prosperity of their citizens through energy supply and security are far better served creating safe, sound investment environments to attract the billions of dollars needed to achieve their goals.

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COVER STORY

CRACKING THE CODE: THERMAL INSULATION IN ETHYLENE PLANTS

John Williams, Aspen Aerogels, USA, discusses the root causes of insulation degradation and suggests ways to improve thermal performance in ethylene service.

Ethylene is the most important intermediate in the petrochemical value chain, and its production is uniquely sensitive to thermal insulation performance. A typical 1 million tpy cracker complex can have 180 000 m^2 of insulated piping and equipment. That insulation scope is comparable to a mid-size oil refinery, despite processing barely one-tenth of the product volume. Part of the reason for this is that temperatures in an ethylene unit are extreme, ranging from -200 to 850°C (-328 to 1560°F) – more than twice the span of a typical refinery (Figure 1). Another reason is that ethylene is difficult to store and transport, so crackers tend to be co-located with downstream chemical producers (e.g., polyethylene, PVC, styrene), necessitating long runs of insulated pipe. It is no wonder that nearly 3% of the energy required to produce ethylene is lost through an insulated surface.[1] This is the ideal performance for a brand new system, but an existing plant – of which there are nearly 300 globally – can lose more than twice that, along with the commensurate carbon dioxide (CO_2) emissions.

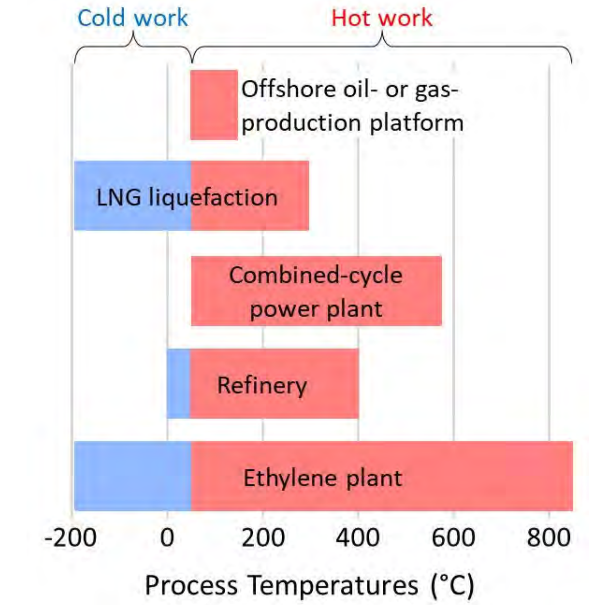


Figure 1. Operating temperatures in different industrial facilities.

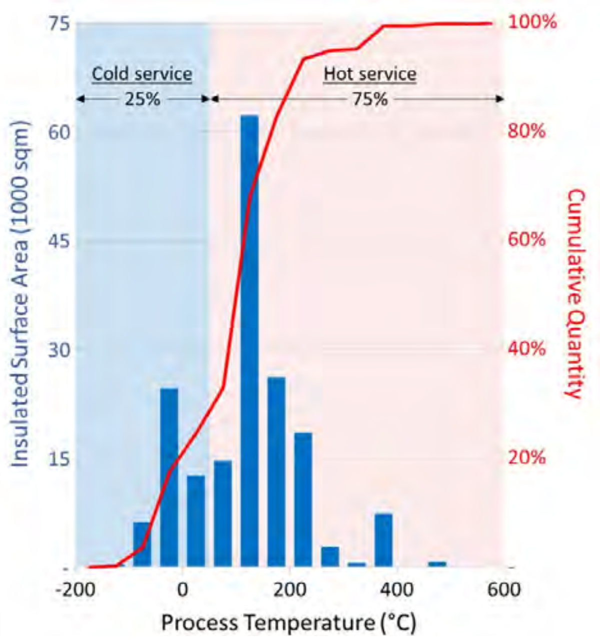


Figure 2. Insulation in a typical 1 million tpy ethylene plant.

Figure 3. Degraded hot insulation.

Roughly 25% of the insulated surface area in an ethane cracker is for cold or cryogenic service (see Figure 2), with the remainder being for hot work (i.e., above-ambient service temperatures). This article will look at the root causes of degradation for both types of insulation, diagnostic indicators to look for, and ways to improve thermal performance in ethylene service.

Hot insulation

Insulators speak of the three horsemen of insulation damage – heat, water, and mechanical abuse – but a more accurate census might be one horseman and its two attendants. While heat and mechanical abuse can as much as halve insulation resistance through sagging, crushing and reduced thickness, this effect is highly localised, and is barely felt at the system level. Their more serious offence is ushering water into the insulation space by opening up seams in the jacketing (see Figure 3). From these breaches, water spreads via both liquid- and gas-phase transport until even areas that are far away from the damage become wet. While water does not 'want' to remain inside a hot insulation system – it is always in the process of vaporising or draining away – the local environment usually provides frequent replenishment via precipitation, deluge testing, or cooling tower drift. In this way, old, hot insulation gradually enters a quasi-equilibrium state where moisture in-flows and out-flows balance over time to produce an average degree-of-wetness across the entire system.

Severe insulation wetness can increase apparent thermal conductivity, and therefore heat loss, by a factor of 20 or more. While that degree-of-wetness will decay with distance away from a jacketing breach, water's influence can reach for tens or even hundreds of meters. Aspen Aerogels has conducted dozens of kilometer-scale steam system audits around the world, using plant process data (inlet and outlet temperatures, pressures, and flow rates) to diagnose insulation underperformance. Averaged over the entire hot insulation system, a doubling of heat loss after 5 – 10 years in service should be expected for water-absorbent insulation materials such as mineral wool, calcium silicate, and fibreglass.

That loss factor, if applied to a 1 million tpy ethylene plant, would cost US$3.8 million/yr in unplanned fuel usage.[2] For a facility that likely spent less than US$10 million on its entire inventory of hot insulation material, a US$3.8 million annual loss from underperformance is a bitter pill to swallow. This scenario is like buying the material again every two-and-a-half years, and that is on top of the extra 40 tpy of CO_2 emissions such underperformance would generate.

One other thing that has been learned from these audits is that even catastrophically-failed insulation systems are not easily diagnosed. To all outward appearances, the insulation will be mostly intact, with perhaps a few damaged or missing sections.

Figure 4. Degraded cold insulation.

Figure 5. Rusted pipe supports.

Infrared scans do not tell us much either, as they are defeated by most metallic jacketing systems and, even when not, the data is sparse and requires too much post-processing to be broadly useful. Process monitoring of end-to-end temperature drop only works on a small subset of the 100+ km of piping in these plants and, even then, is rarely done. The incremental demand that insulation places on steam and electrical utilities can easily be obscured by the normal ebb and flow of plant life. Systemic failure of hot insulation lives beneath the noise floor; its effects are felt, but rarely identified.

Cold insulation

Cold insulation at least has the courtesy to announce its own demise. The jacketing of a healthy cold or cryogenic insulation system will generally run a few degrees cooler than the ambient temperature. As the insulation begins to fail, that surface temperature will gradually drop through a number of visual tell-tales. First, it will hit the dew point temperature, at which point condensation begins to form on the jacketing. Initially, this happens mostly during morning hours, when the air is cool and still, the sun is low, and the relative humidity is high. As failure progresses, surface wet-time will increase from just a few hours per day to the majority of the operating time. This leads to the second tell-tale, which is mold and algae growth on the jacketing (see Figure 4). Surrounding areas, such as concrete walkways and steel pipe supports, can also suffer from their newfound proximity to liquid water (see Figure 5). The final indicator is when the jacket temperatures become cold enough for ice to form on the surface (see Figure 6). At this point, a mere insulation problem has metastasized into a safety problem, by way of unplanned structural loads, trip-and-slip hazards, and falling blocks of ice.

As with hot insulation, water is the chief culprit, but the mechanism is very different. Water generally enters these systems as ambient humidity, compelled by the difference in vapour pressure between the warm exterior and the cold interior. Unlike with hot systems, water does want to be there and, once in, will never leave of its own accord. As a result, the failure of cold insulation systems usually does not plateau at some interim state of saturation. Water is persistent, and is not satisfied until it has filled every nook and cranny within the insulation space. Since water and ice have thermal conductivities that are one to two orders of magnitude greater than the typical cellular-glass or polyurethane/polyisocyanurate-foam materials, the increase in local heat gain is enormous (see Figure 7).

That said, cold insulation is usually compartmentalised with vapour stops. These are periodic barriers to mass transport running parallel to process surfaces. Vapour stops prevent, or at least slow, insulation failures from spreading beyond the local defects from whence they began. Failures of cold insulation, even if frequent, are usually localised to 4 – 8 m stretches of pipe.

Furthermore, due to the difficulty of designing for condensation control, the baseline rate of heat flow through cold insulation systems is much lower than that of hot systems. As a result of these two factors, the biggest impact of underperforming cold insulation is not gross energy usage; it is production.

Every excess Joule entering a cold insulation system either shifts the process away from its ideal operating condition, or must be removed with a refrigeration system. While refrigeration systems have some ability to follow an increased demand, they are not as flexible as, say, steam systems – where boilers can be throttled up or supplemented with external supply. As a result, the refrigeration plant often becomes a bottleneck in cold process systems. When heat gain through the insulation exceeds refrigeration capacity, production quality and quantity can suffer. When that happens, everyone starts paying attention to insulation.

Figure 6. Icing on cold insulation.

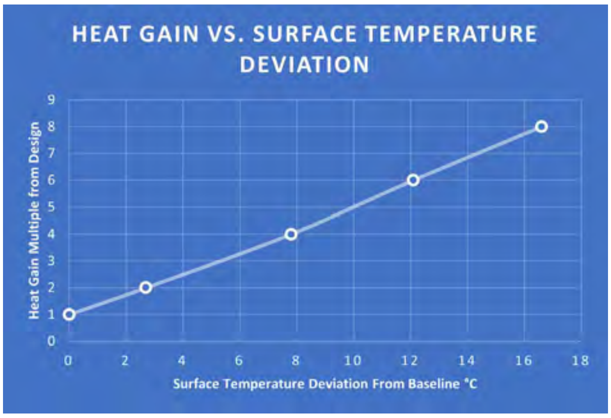


Figure 7. The energy impact of surface temperature deviations.

What to do about it

Since water is the primary driving force behind both hot and cold insulation failures, it makes sense to begin with materials that are durably resistant to moisture. In the world of hot insulation, both expanded perlite and flexible aerogel blanket materials (e.g., Pyrogel®) have a long and established track record in this regard. Their inherent hydrophobicity not only helps prevent the onset of energy losses, but also mitigates corrosion under insulation. Pyrogel in particular has the additional feature of being breathable, capitalising on water's natural inclination to exit any system running warmer than ambient.

For cold insulation, flexible aerogel blanket materials such as Cryogel® again bring a unique set of material- and system-level properties to the problem of moisture ingress. Cryogel's multi-layer designs bring 6, 9, even 12 redundant sheets of vapour-retarder material to cryogenic systems, providing moisture defence in depth. Even without any vapour barriers at all, Cryogel's nanoporous structure is simply too fine-scaled to allow for the internal formation of ice when tested down to -196°C (-320°F). Finally, Cryogel's flexible nature eliminates the need for expansion-contraction joints – a frequent failure point for rigid-foam systems – and does not suffer brittle fracture when cold.

One US ethylene producer used a turnaround to replace ageing cellular glass insulation with Cryogel in its cold separation unit. After restart, the company found that one of the main columns was running 5.6°C (10°F) colder, and within a year it was setting plant production records. The company also noticed that most of the throttling, reflux and other controls used to compensate for atmospheric conditions were no longer necessary. The now well-insulated unit cared about the weather no more.

Conclusion

Insulation materials generally consume less than 1% of a new ethylene plant's CAPEX, but exert an outsized influence on that plant's performance, profitability, and environmental footprint. For the owners and engineers of new-build crackers, it is wise to consider this unique sensitivity to insulation performance during the FEED process; what seems cheap today could become very expensive within just a few years. For those operating existing plants, keep an eye out for the tell-tale indicators that have been discussed in this article. When you do see them, consider what flexible aerogel blanket insulation could accomplish in your next turnaround.

Notes

1. 26 GJ/t, excluding feedstocks. Source: WORRELL, E., et al, 'Energy Use and Energy Intensity of the US Chemical Industry', Lawrence Berkeley National Laboratory, Report No. 44314, (April 2000).
2. Assumes an effective cost of energy of US$16/MWh.

AN INSIGHT INTO INDIA'S SULFUR SECTOR

Bhaviksinh Mahida, IPCO, India, outlines why demand for sulfur is set to grow across India in the coming years, and the benefits of turnkey sulfur production and handling solutions.

India currently has the sixth largest economy worldwide, and it is predicted to overtake Germany and Japan by the end of the decade. UN figures suggest that at the end of April 2023, the population of India clicked past 1 425 775 850 – a moment that saw the country overtake China as the world's most populous country.

The seismic change taking place on the subcontinent is mirrored in India's refining sector. The country is home to the world's largest oil refinery, Reliance Industries' 1.24 million bpd Jamnagar refinery, and the sector as a whole is investing to meet the needs of markets at home and overseas (refined petroleum is India's number one export, worth US$49 billion).

Figure 1. Discharge end of Rotoform HS pastillation units.

Figure 2. Drum granulation process.

Figure 3. Circular stacker reclaimer for storage of solid sulfur pastilles.

Solidification of liquid sulfur

In recent years, the demand for sulfur in the refinery sector has been growing steadily. This can be attributed to several factors such as increasing demand for cleaner fuels, and the expanding global energy industry. The use of sulfur compounds in the refining process helps to reduce the sulfur content in the end product, thereby making it a cleaner fuel. This is particularly important in the production of gasoline, diesel, and jet fuel.

Sulfur is a byproduct of refining crude oil, and it is usually extracted from crude oil through a process called 'sour gas processing.' The sulfur that is extracted during this process is usually in the form of hydrogen sulfide (H_2S) gas, which is then converted into elemental sulfur.

In addition to the demand for cleaner fuels, government regulations have also contributed to the growing market for sulfur in the refinery sector. Many governments around the world have implemented regulations that mandate lower sulfur content in fuels. For example, the International Maritime Organization (IMO) has implemented regulations that require ships to use fuels with a maximum sulfur content of 0.5%, down from the previous limit of 3.5%.

India is the third-largest consumer of petroleum products globally, and its consumption has been on a steady rise over the last decade. The Indian refining sector has observed an upsurge in sulfur production due to this escalating demand for petroleum products. The Indian government has also been promoting the use of clean fuels, which has led to an increase in the production of ultra-low-sulfur diesel (ULSD) and gasoline. The production of ULSD and gasoline involves the removal of sulfur, which further adds to the demand for sulfur.

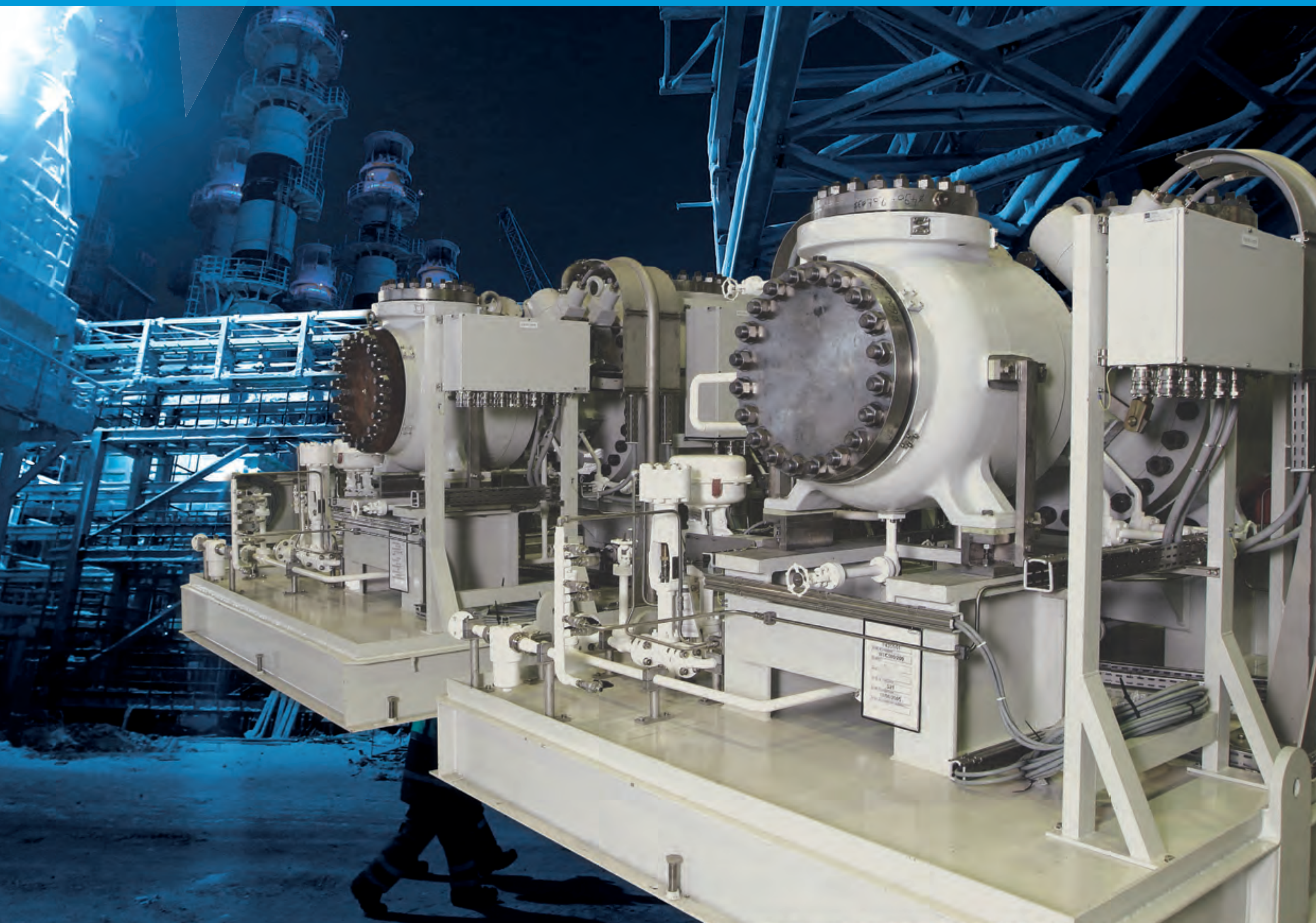
The Indian refining sector produces approximately 6 – 7 million tpy of sulfur, and the demand for sulfur in the country is expected to grow at a compound annual growth rate (CAGR) of approximately 3 – 4% over the next few years. This growing demand can be attributed to several factors.

Firstly, the Indian government has been promoting the use of clean fuels such as compressed natural gas (CNG) and liquified petroleum gas (LPG), as well as the use of electric vehicles. The rise in clean fuels has led to a reduction in the emission of harmful pollutants, and it has also resulted in the production of ultra-low-sulfur fuels.

Secondly, the Indian fertilizer industry is one of the largest consumers of sulfur, which is an essential nutrient for plant growth. The Indian government is currently promoting sulfur bentonite, a sulfur-based fertilizer.

Thirdly, the Indian chemical industry is a significant consumer of sulfur, which is used in the production of various chemicals such as sulfuric acid, sodium sulfate, and carbon disulfide. The Indian chemical industry has been growing steadily over the past few years, and this has led to an increase in the demand for sulfur.

Finally, the Indian refinery sector has been investing significantly in the upgrade and modernisation of its



refineries. This involves the installation of new technologies that produce high-quality fuels with low sulfur content. Almost all major refineries in India are undergoing this process, which has resulted in large sulfur production and handling projects, for which IPCO is providing a turnkey solution from upstream, process equipment and downstream handling as a complete package. One of the significant advantages of these projects is the localisation of the major peripheral equipment and services. This approach has helped to keep the overall project costs in check while ensuring improved control over quality, and timely delivery. Turnkey solutions offer complete project management from design to commissioning, including process design, equipment selection, procurement, fabrication, construction, and start-up.

Case study

IPCO carried out a project at Reliance Industries' Jamnagar refinery in 2009. IPCO's scope of supply covered all upstream and downstream equipment associated with the solidification system, including cooling water pumps, sulfur pumps, the cooling tower, conveyors, a moveable silo filling system, and six siloes. IPCO also delivered and installed all related instrumentation, cabling and piping, as well as a programmable logic controller (PLC)-based control system with frequency drives.

Since 2008, IPCO has carried out work on a number of projects with a similar scope of supply, including for Mangalore Refinery and Petrochemicals Ltd, Indian Oil Corp., Nayara Energy, and Bharat Petroleum.

Sulfur solidification

For small- to mid-size capacity solidification requirements, IPCO's Rotoform system is a single step, liquid-to-solid process. Free-flowing pastilles of uniform size and shape are easy to handle, while high bulk density offers an advantage for storage and handling. The operating principle of the system has remained essentially unchanged since the first model was introduced in the 1980s, although it has undergone improvements and now includes models designed for sulfur processing, including the Rotoform S8 with a capacity of 5.5 tph, and the Rotoform HS, a high-speed model with a capacity of up to 11.5 tph.

Figure 4. IPCO's pitch solidification plant.

Figure 5. Solid energy: pitch flakes.

The system consists of a heated cylindrical stator, which is supplied with molten sulfur via heated pipes and a filter, as well as a perforated rotating shell that turns concentrically around the stator. Drops of the product are deposited by the nozzle bar across the whole operating width of a continuously running stainless steel belt.

A system of baffles and internal nozzles built into the stator delivers uniform pressure across the width of the belt, ensuring even flow through all of the perforated rotary shell's holes. This ensures that the pastilles are of uniform size, from one edge of the belt to the other.

The rotational speed of the unit is synchronised with the speed of the steel cooling belt to allow for a gentle deposition of the liquid droplets onto the moving belt. Heat released during cooling and solidification is transferred via the steel belt to cooling water sprayed underneath.

After the drop has been deposited onto the steel belt, some product residuals may remain on the outer shell. A heated refeed bar forces this product back into the Rotoform and keeps the outer shell clean.

The solidified sulfur droplets are discharged as hemispherical pastilles at the end of the cooling system. To eliminate the possibility of damage to the pastilles during discharge, a thin film of silicon-based release agent is sprayed onto the steel belt.

The process offers a number of environmental advantages. As the cooling water and sulfur do not come into contact, there is no need for a water treatment system at the solidification stage; the water can simply be re-cooled and used again.

Solidification takes place rapidly – usually in less than 10 sec. – so there is little time for H_2S to escape, resulting in very low emission values and no need for additional equipment such as scrubbers or burners.

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Figure 6. IPCO's paraffin wax pastillation process.

Similarly, low dust levels mean that exhaust air treatment with wet scrubbers or cyclones is not required.

High-capacity drum granulation

If higher capacity sulfur solidification requirements are required, different drum granulation systems are available.

In IPCO's SG range, seed or nuclei particles of solid sulfur are generated externally by freezing sprays of liquid sulfur in a water bath at controlled pressures in order to form the desired size range. These particles are then augured into a slowly rotating drum with appropriately-placed flights attached to its inner surface. The flights create curtains of particles inside the drum, and gently move them towards the discharge end.

As the nuclei particles travel along the drum, they are progressively enlarged to the required size by means of sulfur sprayed from a bank of nozzles running the length of the drum. The temperature in the drum is moderated by the evaporation of water from spray nozzles located inside the drum.

This is a single-pass process, which eliminates the need for screens or recycle conveyors to send sulfur back through the drum.

A fan is used to draw a stream of air through the drum to sweep out the water vapour as well as any fugitive dust inside the drum. The dust is scrubbed out of this exhaust stream using a wet scrubber before the process air stream is released to the atmosphere.

The underflow from the wet scrubber cyclone is pumped to the same settling/dewatering tank that is used to generate the seed particles. Here, the fines settle out and are augured up along with the sulfur particles generated by the seed generator sprays.

A simple design with minimal rotating equipment enables continuous operation without the requirement for routine shutdown, while the horizontal 0° drum minimises stress to keep maintenance requirements low. Sulfur 'pre-conditioning' is not required, and no solid waste streams or liquid effluents are produced.

This spherical shape of the granules – along with the repeated spraying and cooling of thin layers of molten sulfur as they pass through the granulator – accommodates the natural shrinkage of the product as it completes the transition from melt to solid, without weakening the product.

Solidification of liquid pitch

The Indian government has also been promoting the production and utilisation of bottom of the barrel products, including solvent deasphalting (SDA) pitch, through various policies and initiatives. One such initiative from the Indian Ministry of Petroleum is the Sustainable Alternative Towards Affordable Transportation (SATAT) scheme, which aims to promote the production of compressed biogas, bio-CNG, and bioethanol from various sources, including bottom of the barrel products.

The liquid pitch is typically solidified in the form of flakes, and used as 'solid energy' in power plants.

Solidification of liquid paraffin wax

Another product handled in refineries is paraffin wax. IPCO has supplied several pastillation systems to refineries, including those in Chennai, Digboi and Numaligarh, in India. The wax pastille is the ideal form for easy storage and transportation. Paraffin wax is used as a base material in the chemical and cosmetic industry.

In this segment, IPCO can also supply solutions including product pump, piping, filtration, pastillation unit, and downstream packaging equipment.

Turnkey solutions and engineering partnerships

While process efficiency and reliability are key to end users, the ability to offer complete project management from design to commissioning is also beneficial.

IPCO has become a partner to several international engineering companies that service the petrochemical industry. Activities range from cooperation during front-end engineering design (FEED) to engineering, procurement and construction (EPC) contracts; and turnkey solutions include liquid sulfur supply, solidification and downstream handling of solid sulfur, as well as utility equipment and control systems.

This ability to supply all major peripheral equipment and services on a one-stop-shop basis also helps to keep overall project costs in check while ensuring control over quality and timely delivery. India is one of more than 30 countries in which IPCO has an on-the-ground service presence, and this has been another key factor in building long-term relationships across this sector.

H_2S removal solutions

Jim Aiello, Merichem Company, presents a number of solutions for removing hydrogen sulfide (H_2S) from natural gas.

Historically, sour liquid and gas reserves were left undeveloped because of the technical difficulties and costs associated with extraction and processing. Sour streams can cause corrosion, including sulfide stress corrosion cracking, in pipelines in particular. Additionally, appreciable levels of hydrogen sulfide (H_2S) can be lethal – even at relatively low concentrations.

The heterogeneous composition of natural gas varies depending on the location of the wells and the underlying biomass and burial history. H_2S and carbon dioxide (CO_2) are natural contaminants at widely varying concentrations in both oil and natural gas deposits, as well as in process streams. Because sour liquid and natural gas streams require special care and handling, liquid redox and extraction solutions are necessary for removing sulfur compounds from these streams.

This article will present two case studies to illustrate the importance of removing H_2S from refineries/biorefineries, and the technologies selected to do so.

Case study 1

A major refinery in Midwest US (PADD 2) was producing a high volume of finished products, including gasoline, with a throughput capacity of approximately 170 000 bpsd. Refinery personnel were evaluating capital scope options and requirements for manufacturing gasoline with 10 ppm sulfur to meet the US Environmental protection Agency (EPA) Tier 3 regulations. It was determined that the total sulfur content of the butane/butylene (BB) stream would need to be maintained at less than 10 ppm. To allow for inert sulfur compounds already present in the hydrocarbon feeds, the sum of unextracted acidic sulfur and back-extracted disulfide oil would need to be even lower (3 ppm or less as sulfur). The untreated BB stream had a design throughput of 13 000 bpsd and total mercaptans (RSH) of 222 ppmw as sulfur.

While it is relatively easy to reduce extractable RSH in the product to 1 – 2 ppm as sulfur, one of the most significant challenges in caustic treating is preventing the resulting disulfide oil (DSO) from returning to the hydrocarbon stream. Typically, the DSO is both entrained and dissolved in the oxidised caustic. The colloquial term for the DSO, which returns to the treated hydrocarbon, is 're-entry sulfur' or 'back extraction'.

To achieve the ultra-low-sulfur requirements of the refinery, Merichem Company's REGEN® ULS technology was introduced to significantly reduce DSO back extraction in order to achieve total sulfur product specifications of below 10 ppmw.

Determined commitment to teamwork by the client and company resulted in the refinery meeting its requirements for manufacturing 10 ppm sulfur product in order to align with EPA Tier 3 regulations for gasoline.

Merichem Company's technology significantly reduced the sum of mercaptans and DSO as sulfur to lower than 2 ppmw in the product stream.

The unit handled turndown scenarios well, and has even

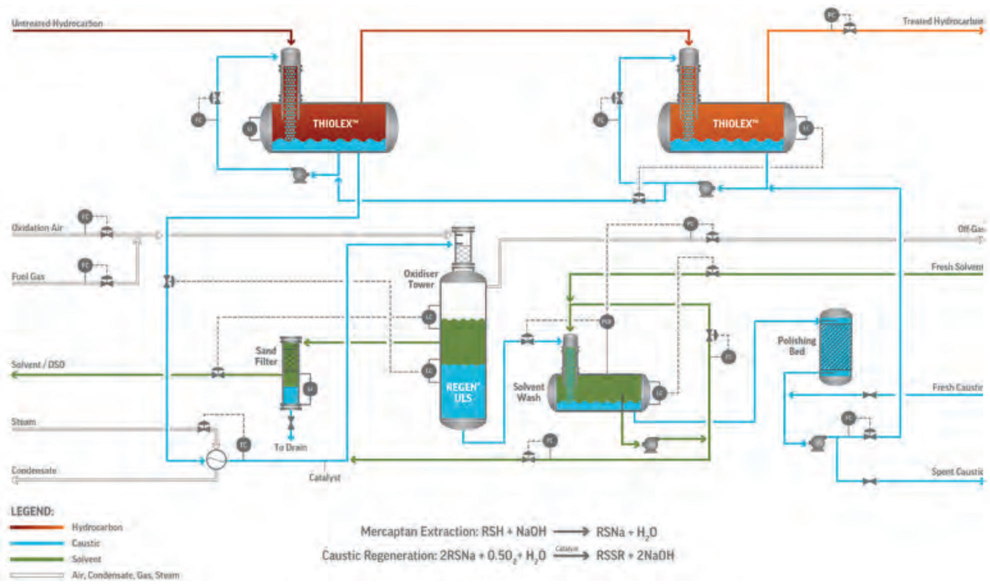

Figure 1. Mercaptan removal for light hydrocarbons with caustic regeneration for ultra-low-sulfur product.

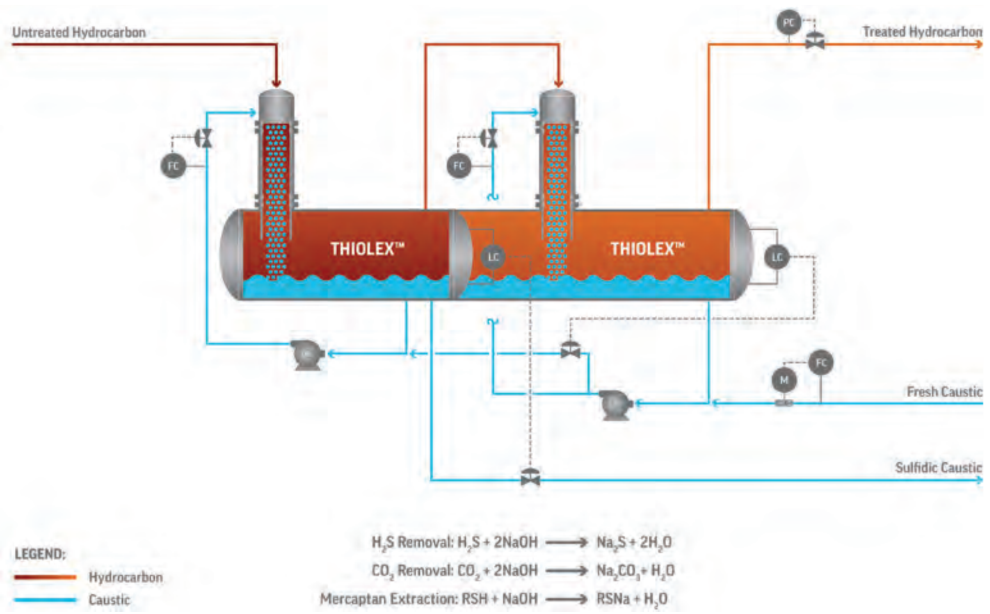

Figure 2. Sulfur removal unit for light hydrocarbons.

handled up to 20% C5+ material in the feed, with the only impact being increased caustic consumption. On a day-to-day basis, operator involvement is minimised to monitoring levels, pressures, flows and temperatures, with occasional caustic batching and catalyst additions.

In utilising this technology, the BB stream was treated with regenerated (lean) caustic to extract acidic sulfur components. REGEN ULS regenerates the spent caustic from the THIOLEX unit while removing almost all DSO, which results in ultra-low sulfur levels being obtained in the treated butane product. The combined technologies reduced the total DSO back extraction to only 1 – 2 ppm as sulfur, which resulted in a much lower total sulfur product specification.

The technological details

THIOLEX utilises caustic soda as the treating reagent to remove acid gas and mercaptan compounds from liquid and gas hydrocarbon streams. In conjunction with the FIBER FILM® Contactor mass transfer technology, it reduces total sulfur content in hydrocarbon streams in order to meet customer specifications, while simultaneously offering design and operational flexibility.

The highly-alkaline pH of the caustic solution reacts with the sulfur species (most notably, mercaptans) to form water-soluble, ionic compounds, which preferentially move into the caustic phase. In conjunction with a proprietary retaining cylinder packed with fibres, this technology improves mass transfer between the hydrocarbon and caustic. The process is continuously renewed as the wet fibres are preferentially wetted by the caustic phase in the caustic extraction process. Hydrocarbons flow through the shroud parallel to the caustic phase, where the H_2S and mercaptans are extracted into the caustic phase. The two phases disengage in a small separator. Where economics dictate, the caustic is sent to a regenerating system, wherein the spent caustic is regenerated using air and catalyst, which converts the extracted mercaptans to DSO. The disulfides are removed from the caustic by a solvent wash system, which also utilises a mass transfer mechanism.

Because the mass transfer mechanism creates an interfacial surface area that is orders of magnitude larger than conventional processes, the extraction technology improves the efficiency of mass transfer, allowing impurities to diffuse between phases with little or no emulsification, carryover, or high pressure drop.

To achieve the ultra-low-sulfur requirements of the refinery, a regeneration and reuse technology for ultra-low sulfur is utilised, which significantly reduces DSO back extraction in order to achieve total sulfur product specifications of below 10 ppmw. This process combines two differing technologies in a way that forces the DSO to fully separate from the regenerated caustic.

In the ultra-low-sulfur system, the mercaptide-rich caustic is oxidised on a fixed catalyst bed. The resulting DSO is then removed from the caustic using bulk phase separation and decanting; solvent washing; and adsorption on a fixed bed to yield the ultra-low-sulfur lean caustic that is recirculated to the THIOLEX unit for continuous treating. The technology super-regenerates the mercaptide-rich caustic and returns a lean caustic that is almost free of DSO.

Case study 2

One of the most innovative biorefineries in Europe was launched in 2019. The plant has a processing capacity of over 700 000 tpy, and can treat an increasing quantity of used vegetable and frying oil, animal fats, algae, and waste/advanced byproducts to produce high-quality biofuels.

Part of the plant's design basis is to remove 99.9% of sulfur before CO_2 is emitted into the atmosphere, but varying operating conditions result in fluctuating H_2S and CO_2 concentrations and volumes leaving the upstream amine units. As such, the plant required a highly-flexible sulfur recovery process to handle the range of feed gas conditions. Because Merichem Company's LO-CAT® technology maintains consistent sulfur removal efficiency at turndown conditions, and has no minimum H_2S concentration requirement, the refinery chose this for sulfur removal and recovery.

An autocirculation process is employed for processing non-combustible gas streams. At another European biorefinery, a direct treatment processing scheme is in place for treating combustible gas streams and product streams that cannot be exposed to air. To accommodate the plants' varying sulfur removal requirements, specialised equipment configurations are in place in order to meet the environmental specifications of the EU Renewable Energy Directive.

The biorefinery has been such a success that a company is considering building another that is capable of producing 500 000 tpy hydrogenated biofuel, as well as a plant for the production of hydrogen from methane gas.

The technological details

LO-CAT is designed to remove H_2S from streams that produce 0.5 – 20 tpd of elemental sulfur. Its liquid redox system uses a chelated iron solution to convert H_2S into innocuous, elemental sulfur. Based on regenerative chemicals, it is both reliable and flexible as compared to biological treatment, with no liquid waste streams, and it has been used to remove H_2S from gas streams since the 1970s.

With more than 80 operating units across the globe, the technology can remove over 99.9% of the H_2S from most gas streams at ambient to moderate temperature, and moderate to high pressure gas streams. It can treat any gas stream containing H_2S, and is financially-advantageous when scavenger use becomes too expensive. The 'sweet spot' of the sulfur recovery technology application ranges from 0.5 tpd to 20 tpd of sulfur removal.

The system's oxidation reaction is outlined in equation 1:

$$H_2S + 1/2\ O_2 \longrightarrow H_2O + S^{\circ} \qquad (1)$$

The oxidation reaction process is sub-divided into two parts, referred to as redox, which is an acronym for the step one 'reduction' process, and step two 'oxidation' process as follows:

- Step one: H_2S gas absorption, ionisation, and reaction to produce solid sulfur in the liquid solution.
- Step two: the iron catalyst is then oxidised using air, and regenerated for reuse.

The technology's aqueous-based ambient temperature process features a chelated-iron catalyst that is applicable to any gas stream. With removal efficiencies of over 99.9% and up to 100% turndown, H_2S is converted to elemental sulfur.

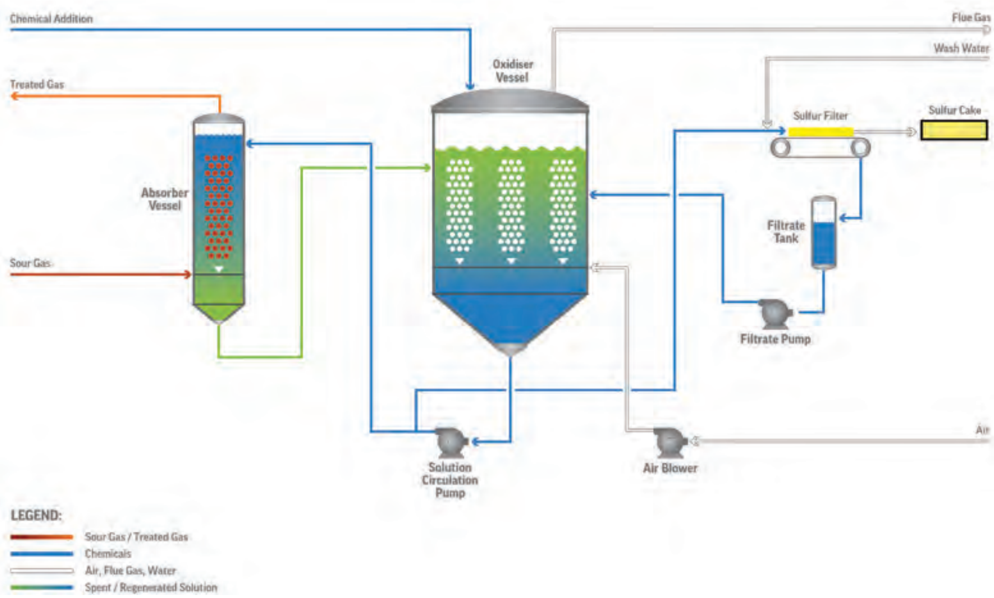

Figure 3. Direct treatment process for H_2S removal from sour gas streams.

Conclusion

Oil and gas refining is a complex undertaking. The aim is to transform unusable crude from its natural state into useable, emission-compliant products for heating homes, fuelling vehicles, and producing petrochemical plastics. Recovering sulfur using chemical-based solutions with no biological or hazardous waste, and with reduced caustic waste, is judicious, efficient and economical, and is an environmentally-friendly green technology.

BREATHING NEW LIFE INTO AN OLD SRU

Scott Kafesjian and Quinn Kotter, Wood, USA, detail how improvements in reliability, operability, safety and performance have helped to revitalise a vintage sulfur recovery unit (SRU) in North America.

The subject of this article is a recent revamp project executed by Wood. A North American refiner had two operating sulfur recovery units (SRUs): SRU A started up in 1974 and SRU B, a modular unit designed by Wood, started up in 2006. Each SRU included a three-reactor Claus section, incinerator, and caustic scrubber. With the installation of an NaHS unit in 2013 to treat another sour gas stream, SRU A became a non-essential unit, maintained for safe operation, with minimal investment otherwise.

A change in the refinery operating strategy elevated the importance of SRU A due to higher projected crude throughput and increased crude sulfur content. Accordingly, SRU A capacity was projected to become essential, and high availability was required to enable the desired future operation of the refinery.

Major investment in sulfur units (usually regarded as cost centres) is difficult to justify, which is why SRU A had been somewhat neglected, but the revised strategy motivated and justified the revamp project.

Background

It was clear that, with the escalated role of SRU A, a revamp would be necessary. However, there were many known issues to overcome to meet future demands, including:

- SRU A was only able to process amine acid gas, and not sour water stripper acid gas.
- An obsolete reactor reheat scheme was in place.
- The third Claus reactor had been completely bypassed since early in the life of the unit.
- The sulfur pit was plagued by degraded concrete, and was responsible for excessive fugitive emissions.

- The burner management system (BMS) was antiquated and obsolete.
- Air flow to the SRU was manually controlled due to an out of service air demand analyser (ADA).

Long-term improvements to SRU A were required to ensure its availability and improve performance.

The process scheme prior to the revamp is shown in Figure 1. Highlights of the configuration include:

- A single chamber thermal reactor.
- Two-pass waste heat boiler (WHB) developing steam at 250 psig.
- Sulfur run-down lines at pass 1 and pass 2 WHB plenums.
- Hot gas reheat of the number 1 and number 2 Claus reactor inlet streams (note: the 'hot gas' consists of a portion of the effluent from the thermal reactor mixed with a portion of the gas from the first WHB outlet).
- The number 1 and number 2 sulfur condensers were in a common shell (developing low-pressure steam), and the number 3 sulfur condenser was a boiler feed water (BFW) heater in a separate shell.
- The number 3 Claus reactor was bypassed (piping removed), and the reactor contained no catalyst.
- The ADA was out of service, and air control was manually adjusted based on observed caustic consumption rate.
- Natural draft incinerator after the number 3 sulfur condenser, followed by heat exchange to scrubber effluent before the stack.
- After cooling, incinerator effluent was further cooler in a venturi quencher. It then entered a packed bed scrubber where contact with caustic solution removed sulfur dioxide (SO_2).
- Blowdown from the scrubber was oxidised and routed to the refinery wastewater treatment plant (WWTP).
- A booster blower controlled pressure at the incinerator outlet to maintain draft.
- Blower outlet was heated against the incinerator effluent and routed to the atmosphere via the stack.

Key issues

The initial scope of revamp, identified by the owner, entailed the following:

- Replace end of life/obsolete equipment: the thermal reactor, refractory, acid gas burner, and the sulfur pit.
- Eliminate the ineffective reactor reheat scheme.
- Recommission number 3 Claus reactor.
- Replace ADA and stack continuous emission monitoring system (CEMS).
- Install a new burner management system (BMS) programmable logic controller (PLC) with triple redundancy, in order to meet SIL2.

At the start of the project, it was anticipated that additional scope would be developed, as a unit turnaround (TAR) was scheduled to begin shortly after project kick-off. Inspections planned during this TAR could result in the 'discovery' of additional scope for the project.

The project scope also included consideration of further improvements to safety, reliability, performance and operability, which could lead to recommendations to the owner. These recommendations would then be evaluated based on technical justification and their estimated order of magnitude cost. Numerous improvements were recommended by Wood, based on process evaluation and TAR findings.

Post-TAR, it was planned that the unit would need to operate for approximately two years before the revamp could be implemented in the next planned unit shutdown.

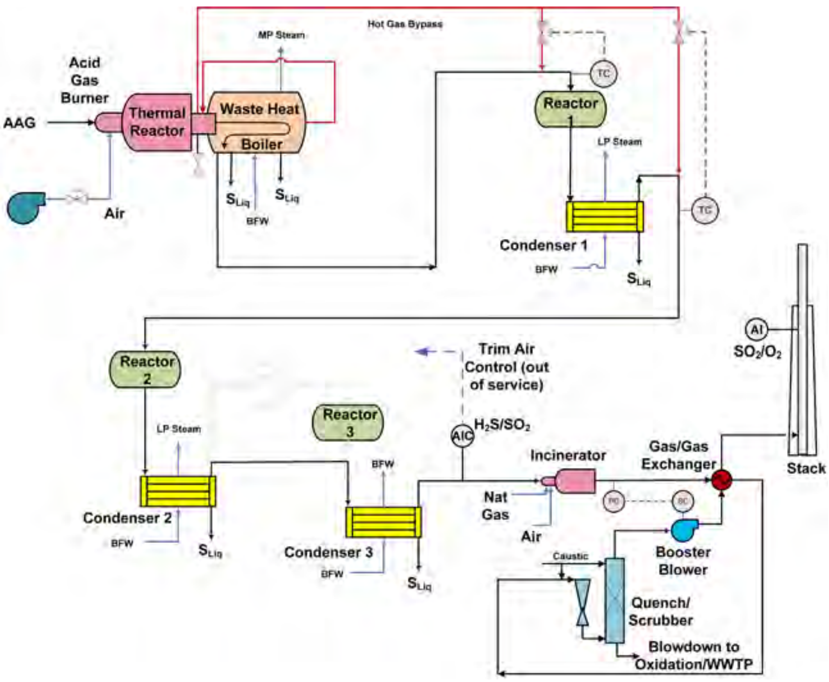

Figure 1. Schematic configuration of SRU A prior to revamp.

Scope evolution

Initial (FEL1) work focused on process evaluation and preparation of a budgetary cost estimate for the revamp, based on identified scope.

TAR findings included items that were not unexpected, summarised in Table 1.

Wood recommended several key process configuration changes, in addition to the initial known revamp scope:

- Eliminate gas/gas heat exchanger.
- Eliminate booster blower.
- Replace incinerator with forced draft design capable of higher operating temperature and providing increased residence time.
- Route incinerator effluent directly to quencher.
- Replace quencher with new venturi designed for higher inlet temperature.

Table 1. TAR findings and resolution			
Item	**Finding**	**Likely cause**	**Action**
Thermal reactor refractory	Degraded	High temperature, rapid temperature changes	Repair
Thermal reactor shell	Wall thinning	Acid dew point corrosion	Repair/patch
Thermal reactor shell	Wall bulge	High temperature exposure	Repair/patch
Acid gas burner	Tip damaged	High temperature exposure	Replace
Waste heat boiler	Tube wall thinning	High temperature exposure, corrosion	None, acceptable Replace inlet ferrules Replace tubesheet refractory
Gas/gas heat exchanger	Tube leaks	Acid dew point corrosion	Plug leaking tubes at ends
Booster blower	Corrosion	Acid dew point corrosion	None
Stack refractory	Extensive damage	Temperature cycling	Partial repair
Stack wall	Corrosion	Acid dew point corrosion	Repair

- Replace scrubber packing with more efficient, lower pressure drop packing.
- Replace degraded stack with a higher-metallurgy, smaller-diameter stack, supported by existing structure.
- Improve thermal reactor air flow control algorithm to stabilise operation and utilise the ADA output.

Figure 2 shows the configuration of SRU A after the revamp. Highlighted changes to the unit configuration include known owner defined changes/additions, and Wood's recommended changes/additions.

Wood also recommended complete replacement of the WHB, however this was not approved due to high cost and a lack of plot space. The TAR also showed an acceptable remaining life of all WHB components.

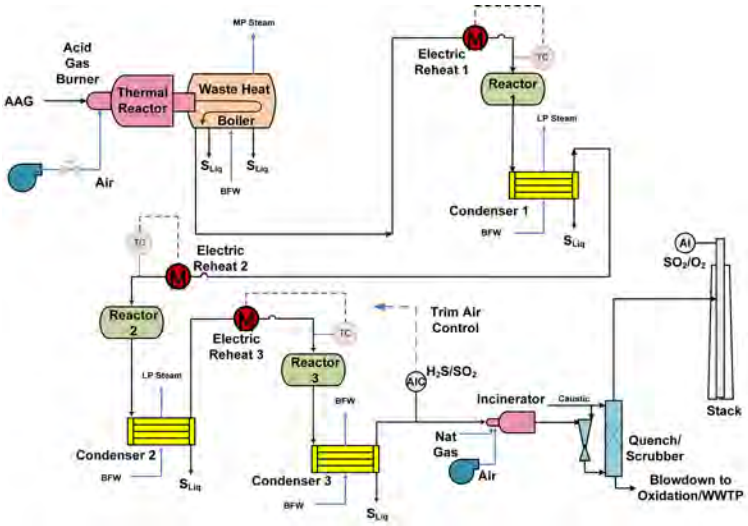

Figure 2. Schematic configuration of SRU A after revamp.

Challenges

As the project progressed through the stage gate process (FEL-1/2/3), challenges were encountered.

Being an older unit that is located at a far end of the refinery, the unit was bounded by roads on three sides and an operating unit on the fourth side, making plot space very limited. Existing equipment was tightly spaced, and existing utility piping was a mix of active and inactive lines, without clear documentation indicating their status.

A significant challenge was that limited elevation was available for sulfur collection by gravity flow. The condensers and the WHB remained in their original locations. The most difficult pipe routing was the sulfur outlet from the second pass of the WHB, which required the nozzle to be reoriented to be tangential to the bottom of the outlet plenum (Figure 3). Sulfur seals were specified with zero elevation change from inlet to outlet (Figure 4). Minimal slope of rundown lines was also specified (1/8 in./ft of running length). The header was located at

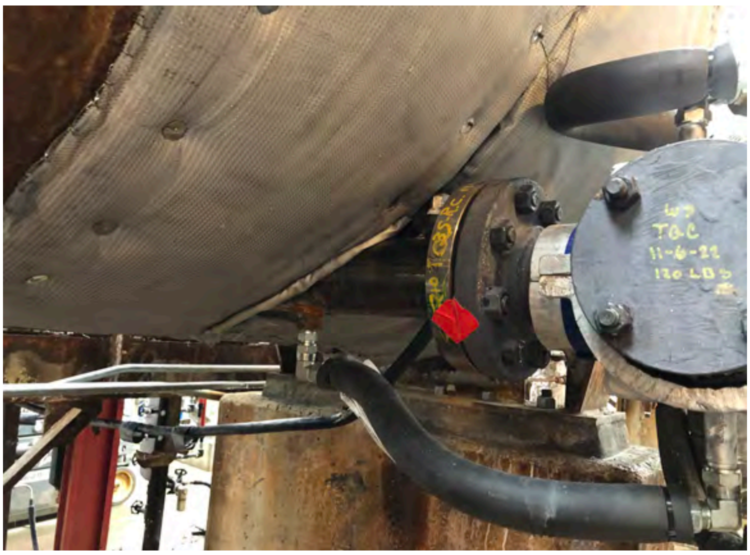

Figure 3. Tangential sulfur rundown nozzle from WHB pass 2 outlet plenum (steam jacketed).

minimum elevation above grade level. All of these steps were necessary to accomplish proper pipe routing to the header.

The COVID-19 pandemic struck part way throughout the project, and the 'new normal' had to be defined, accepted and complied with, while minimally disrupting project progress.

Scope additions and changes were common, as the owner and engineer identified and prioritised 'want to have' and 'must have' items. This required a nimble project team and constant attention to the agreed scope, as well as a steady stream of change notices.

A major addition to the scope took place after the completion of detailed engineering: the unit was to be able to process sour water stripper acid gas feed. This change necessitated the following additions:

- Feed piping for sour water stripping (SWS) gas and amine acid gas rear chamber split.
- Flow measurement and control for SWS gas.
- Preheat of both acid gas feed streams (accomplished with engineered external heating elements).
- Thermal reactor vessel and external thermal protection system (ETPS) size increase and refractory revisions.
- Thermal reactor temperature measurements (internal and external).

Figure 4. Sulfur seal with zero elevation change from inlet to outlet.

Sulfur production capacity is reduced when SWS gas is fed, so there was a derate of unit capacity. Nearly all aspects of the design had to be checked to ensure that there was no impact due to SWS gas processing.

Project progression

The overall project timeline is shown in Figure 5, relative to the project award at T0. The discovery TAR took place approximately three months after the project was awarded, simultaneous with the FEL 1/2 effort and Wood's process evaluation and reconfiguration recommendations. FEL 3 was completed, and detailed engineering began approximately six months after award, followed by equipment bidding and order placement in the following months. Shortly thereafter, COVID-19 protocols were initiated, which inevitably slowed progress as the owner, Wood, and vendors adjusted to the new normal. As a result, detailed engineering duration was months longer than originally scheduled. Shortly after completion of the detailed engineering, the addition of SWS gas processing was requested and additional design work initiated as a result.

Summary and takeaways

A change in refinery strategy placed increased importance on the availability, controllability, performance and safety of an existing 46-year-old SRU.

The originally defined revamp scope was increased due to the following factors:

- The discovery of additional end-of-life equipment during a unit turnaround and inspection.
- Process evaluation and reconfiguration recommendations by Wood for:
  - Improved performance.
  - Reduced atmospheric emissions.
  - Acceptable unit availability and reliability.
  - Personnel and process safety improvements.
  - The addition of SWS gas processing capability.

Cost savings were eventually realised when compared with estimates for the cost of a new unit.

Figure 5. Overall project timeline relative to project award, in months.

As the project progressed, Wood identified many areas for improvement, based on its process knowledge, equipment design experience, and guidance on piping, instrumentation and controls. Following the revamp, SRU A will provide improved reliability, availability, efficiency, performance and safety, and will reduce maintenance, which will enable it to fulfil its elevated role in the refinery.

EXPECTING THE UNEXPECTED

Michael Gaura, AMETEK Process Instruments, USA, explains how to troubleshoot when faced with various issues associated with sulfur recovery unit (SRU) analysers.

Most, if not all, natural gas processing, oil refining, steel production, and even some petrochemical plants contain some type of sulfur recovery unit (SRU) within their operational footprint. As their name indicates, these SRUs are in place to convert and condense (remove/recover) the sulfur that enters the production facility along with the hydrocarbons that are used as a feedstock or as an energy source.

In most areas of the world, sulfur emissions have been aggressively regulated for over three decades, resulting in

SRUs that have been well designed, operated, researched and refined. There are several annual events that bring together a large number of attendees from engineering firms, production plants and process analyser suppliers to specifically discuss how to better manage sulfur recovery plants. A number of articles and research papers have also been published in an effort to provide cleaner, safer and more efficient operations.

Over the past two years, AMETEK Process Instruments has published several articles and papers that focus on general SRU operations; the value of feed gas analysis in sulfur recovery; the role of air demand analysers; key measurement points in tail gas treatment units (TGTUs); and recommendations for more reliable continuous emissions monitoring systems (CEMS). Some of the most consistent requests received by the company are from engineers and end users who want to better understand how they should be interpreting and responding to unexpected analyser measurements. In other words, they already have the analytical systems installed, but want to respond more effectively when needed. This article will seek to help with this.

First, it is important to define the analyser systems, their preferred measurement locations, and their ideal measurement outputs (see Table 1 and Figure 1).

Feed gas analyser (AT1)

Feed gas can be a single stream direct from a hydrogen sulfide (H_2S) and carbon dioxide (CO_2) stripper, or a blend of gas streams exiting an amine stripper, sour water stripper, or other sources.

The compounds and their concentrations should remain consistent unless a new gas stream is introduced, a significant upset occurs in the sour water stripper or scrubbing unit, or one of the blending streams is suddenly removed. Common components and potential ranges can be seen in Table 2.

If the analyser suddenly outputs an increased amount of hydrocarbons, there is a good chance that the upstream stripper is removing them along with CO_2 and H_2S. Typically, this can be confirmed by an increase in the reaction furnace temperature, where the oxygen will preferentially react with the hydrocarbons instead of the H_2S. Sulfur dioxide (SO_2) readings at the air demand analyser may also decrease, and H_2S readings may increase. SRU operations should begin to increase the air feed to the reaction furnace. If not, the oxygen reacting with the hydrocarbons will reduce the amount of created SO_2 that is required for the conversion of H_2S to sulfur in the Claus unit:

$$3H_2S + 3/2O_2 \rightarrow SO_2 + 2H_2S + H_2O \quad (1)$$

$$SO_2 + 2H_2S \rightarrow 3/x\ Sx + 2H_2O \quad (2)$$

The result will be lower recovery efficiency, and potentially some increased SO_2 emissions when the H_2S is converted to SO_2 at the thermal oxidiser (if a TGTU is not present).

End users need to remember to cut the amount of oxygen at the reaction furnace after the hydrocarbon concentrations return to 'normal'. If not, excess SO_2 could continue through the Claus unit and negatively impact the amine or contribute to excess regulated emissions at the emissions stack.

If H_2S levels in the feed gas are decreasing, without an increase in hydrocarbons, air flow to the reaction furnace should be reduced. The air demand measurements will likely also see the levels of SO_2 begin to increase if excess oxygen is not reduced.

Table 1. Key measurements in an SRU

Analyser tag	Commonly referred to as	Location	Measures
AT1	Feed gas analyser	Prior to the SRU reaction furnace	Composition of the gas being delivered to the SRU
AT2	Air demand analyser (or tail gas analyser)	After the final condenser in the Claus unit	Concentration of key gases of interest, after a significant amount of sulfur has been removed in the Claus unit
AT3	Sulfur pit/storage analyser	Head space of sulfur storage	H_2S and SO_2
AT4	TGTU pre-absorber analyser	Quench tower overhead	H_2S and hydrogen
AT5	TGTU post-absorber analyser	Absorber overhead	H_2S, hydrogen, COS, CS_2
AT6	CEMS	After thermal oxidiser	SO_2, oxygen, CO_2, CO, NOx, H_2S

Air demand analyser (AT2)

A 2:1 ratio of H_2S:SO_2 – or often slightly higher – is targeted at the exhaust of the final condenser. By design, the air demand analyser will drive an adjustment in trim air at the reaction furnace to constantly maintain the

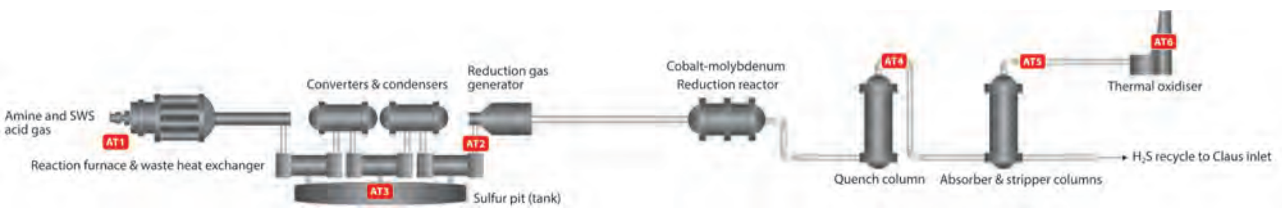

Figure 1. A typical SRU.

plant-specific ratio of $H_2S:SO_2$. It is expected that as H_2S levels increase at the outlet of the Claus unit, SO_2 levels will decrease correspondingly. The opposite is also true: as SO_2 levels increase at the Claus outlet, H_2S levels decrease. This makes sense when one considers the expected stoichiometric reaction that takes place in the reaction furnace and during subsequent conversion to elemental sulfur in the Claus (see equations 1 and 2).

If there is little change in H_2S and SO_2 concentrations over time – at some positive values – there is likely a plug in the probe or the sample system. Some movement is expected in the air demand analyser readings as input H_2S concentrations do change, catalysts age, reaction furnace and reheater temperatures can fluctuate, etc. Loss of aspirator air can also result in stagnant readings as the sample cell is not being flushed with new sample gas.

If there is little movement of the H_2S and SO_2 concentrations over time, and those readings are at zero, this could indicate that H_2S is not being delivered to the reaction furnace, the sample line is plugged, or the analyser optical bench is not operating correctly. In this case, operators should:

- Confirm flow of acid or sour water gas to the reaction furnace.
- Check for alarms on the air demand analyser. Most are designed with internal diagnostics to indicate critical component failure.

Table 2. Common components and potential ranges

Component	Concentration
H_2S	0 – 100%
CO_2	0 – 80%
H_2O	0 – 10%
Total hydrocarbons	0 – 5%
NH_3	0 – 70%

- If flow is confirmed and there are no alarms, challenge the analyser with a gas cylinder that includes H_2S and/or SO_2.

If a significant increase of SO_2 is observed and H_2S levels go to 0, this can be a result of a sudden decrease in hydrocarbons or H_2S in the feed stream. The amount of oxygen present at the reaction furnace is greater than required for proper reactions to occur, and needs to be reduced.

If the opposite occurs, and H_2S levels ramp up and SO_2 levels go to 0, an unexpected increase in feed gas hydrocarbons or H_2S may be occurring. This should be identified by a feed gas analyser, but not all SRUs measure inlet gas stream components and compositions. Proper reaction chemistry requires the amount of air at the reaction furnace to be increased.

It should be noted that these two situations are well understood, and control systems do exist to manage the upsets that are identified with an air demand analyser.

Sulfur pit/storage analyser (AT3)

Sulfur storage areas are monitored to prevent conditions that may lead to an explosion, or to identify whether a smoldering fire already exists. A smoldering fire could be the ignition source for any potential explosion. The use of these analysers is almost entirely to ensure safe containment of the recovered sulfur.

As sulfur is condensed in the Claus unit, some H_2S can be entrained in elemental sulfur. Whilst this is usually not much – in the hundreds of ppm – this H_2S can accumulate and eventually exceed the lower explosion limit (LEL) of 3.25%. So, the sulfur storage areas are continuously swept to prevent accumulation of H_2S above the LEL.

As with an air demand analyser, the concentrations of H_2S and SO_2 are measured and monitored:

- As the H_2S levels increase, the sweep rate must be increased. If the concentrations continue to rise, vents should be checked to ensure that they are not plugged.
- If SO_2 levels are rising suddenly and then falling, this can be an indication that a smoldering fire is periodically present.

In both cases, appropriate safety actions should be taken as soon as the analyte concentrations begin to increase.

TGTU analysers (AT4 & 5)

As per the modified Claus reversible process step, the conversion efficiency is limited and commonly around 96 – 98%, so a TGTU is often installed in the SRU. The TGTU is designed to convert sulfur compounds that exit the Claus unit to H_2S, utilising excess hydrogen and catalyst, and then selectively remove as much of the H_2S as possible in an absorber and return it to the reaction furnace at the front end of the SRU, for reprocessing (see equations 3 – 7):

$$SO_2 + 3H_2 \rightarrow H_2S + 2H_2O \quad (3)$$
$$S + H_2 \rightarrow H_2S \quad (4)$$
$$H_2O + CO \rightarrow H_2 + CO_2 \quad (5)$$
$$COS + H_2O \rightarrow CO_2 + H_2S \quad (6)$$
$$CS_2 + 2H_2O \rightarrow CO_2 + 2H_2S \quad (7)$$

To optimise unit uptime and reduce sulfur emissions, multiple analysers should be present in every TGTU. At a minimum, the H_2S levels before and after the absorber should be analysed, and hydrogen should be analysed at these same locations, to provide a redundant hydrogen measurement in the TGTU.

If the measured levels of hydrogen (typically in the 0 – 5% range) are falling, this could indicate that a couple of abnormal conditions are present:

- Hydrogen is not being introduced into the reaction process.
- Unexpectedly high levels of SO_2 are exiting the Claus unit (can be confirmed by the air demand analyser) and 'using up' the required hydrogen for the conversion to H_2S.

Proper performance of the analyser can be supported by an increase in SO_2 measurements at the emissions stack.

If hydrogen levels are increasing, this could indicate that there is an issue with the catalyst (typically cobalt-molydenum, but others exist); temperature in the reducing furnace is insufficient; or the amount of SO_2 exiting the Claus unit has decreased from anticipated levels. Again, confirmation of changing SO_2 levels can be achieved by checking the SO_2 concentration trends at the air demand analyser.

Changing levels of H_2S levels prior to the absorber is not typically a concern, but these measurements can be used to properly load the H_2S absorber in the SRU.

Measuring the H_2S concentration at the outlet of the absorber provides insight on absorber performance and forecasts what will be arriving at the thermal oxidiser. If the plant operations team sees H_2S levels rising at the analyser located after the absorber, it is good practice to analyse the amine to determine whether it is spent and needs to be replaced.

Finally, measurement of carbonyl sulfide (COS) and carbon disulfide (CS_2) can be performed after the absorber (AT5). Rising levels, without a corresponding change in H_2S and SO_2 concentrations at AT2, may indicate that the cobalt molybdenum catalyst is failing and should be replaced.

CEMS (AT6)

The CEMS is the last analytical measurement in the plant, and measurements need to be reported to regulatory agencies.

If SO_2 levels are increasing, several potential issues could be driving the excess emissions (as aforementioned):

- Poor conversion efficiency in the Claus.
- Loss of excess hydrogen in the TGTU.
- Loss of absorber efficiency in the TGTU.

Instead of doubting whether the CEMS analyser is working accurately, results from other SRU plant analysers should be used for comparison. Issues that originate in the feed gas composition, Claus air ratio management, and/or TGTU operations can result in elevated SO_2 emissions.

If the SO_2 levels are increasing, as well as the thermal oxidiser temperature, there is a good chance that the absorber media needs to be replaced. This can be confirmed with H_2S measurement trends from AT5 (absorber overhead analyser).

If H_2S levels are increasing and SO_2 levels are decreasing, there is likely an issue with the thermal oxidiser.

Conclusion

SRUs are technically-proven, but do require constant monitoring to ensure desired recovery efficiency is achieved, regulatory requirements are met, and safety is maintained. Fit-for-purpose analysers exist and can be part of automated solutions, but the complete system will occasionally require human troubleshooting skills.

Who needs helium?

Lieven Kempenaers and Taco van der Maten, Malvern Panalytical, the Netherlands, look ahead to the updated ISO 13032 standard, and consider the role that next-generation X-ray fluorescence will have to play.

The petrochemical industry is anticipating the imminent publication of the updated ISO 13032 standard, which regulates the acceptable levels of sulfur in automotive fuels, and how to measure them. It is likely that the new standard will represent a downwards revision in the quantity of sulfur permitted, which means that the industry is already preparing to adapt its processes in order to comply.

ISO 13032 deals with very low concentrations of sulfur, measured using the energy-dispersive X-ray fluorescence (EDXRF) methodology. The characterisation of elemental composition at very low levels can also be carried out in the laboratory using wavelength-dispersive X-ray fluorescence (WDXRF), but the more complex equipment that WDXRF requires makes this method less common for use in plants or refining facilities, where a smaller and more robust machine is often more practical. Given the widespread use of EDXRF to control sulfur content at-line during operations, the ISO norm refers specifically to this method.

As sustainability targets come into ever-clearer focus across the industry, and technology evolves to provide more accurate measurements for less cost, more stringent standards are likely to become the norm in the future. In this changing landscape, higher-sensitivity performance will become increasingly important. Being able to characterise elemental composition more accurately opens up greater possibilities for process control, and ensures compliance with future regulations. Companies need to comply with these regulations with an eye on tomorrow, 'future-proofing' their analytical solutions in order to avoid the cost and downtime of multiple upgrades later down the line. Many are also preferring to invest in multi-purpose tools that can add value to their processes in more than one way, or that can be deployed at more than one stage of their processes.

The helium question

It is common for the current generation of EDXRF instruments to rely on the use of helium gas as a consumable resource in order to boost their sensitivity.

Figure 1. Epsilon 1 ULS.

However, helium is expensive at best and can be completely inaccessible in some regions, at worst. This makes processes that rely on it expensive to run, and potentially vulnerable to disruption – depending on the supply chain. Ideally, companies would be able to phase out the use of helium as a consumable in XRF analysis altogether. However, in order for this to be possible, an accessible alternative is required.

Technology is rapidly adapting to the industry's needs, as it always does, with more accurate instruments becoming more easily available than in the past. In particular, EDXRF analysers are beginning to close the gap with their WDXRF counterparts in terms of accuracy, which is good news for companies looking to keep costs low.

To investigate possible solutions to the twin concerns of future-proofing and lowering running costs, Malvern Panalytical carried out a case study looking at EDXRF characterisation of low-level sulfur content without helium. The instrument used in the study was the Epsilon 1 Ultra Low Sulfur (ULS) (see Figure 1), and the aim was to find out whether it was possible to measure sulfur with enough accuracy to comply with the ISO 13032 norm, without using helium to boost the detector's sensitivity. It was also crucial that any results met the requirements for repeatability, so that they would be useful in the real world.

How sensitive is sensitive enough?

In order to comply with the norm, companies must use an instrument that is capable of meeting the following precise requirements for a 10 mg/kg sulfur in fuel standard:

$$(R_s - R_b)/\sqrt{(R_b)} \geq 1.3 \quad (1)$$
$$C_v\,(R_s) < 5\% \quad (2)$$

Where:

- Rs is the gross count rate (cps) for a sulfur region of interest for a 10 mg/kg sulfur standard.
- Rb is the gross count rate for the same region of interest for a blank sample.
- Cv (Rs) is the coefficient of variation (relative standard deviation) based on 10 individual measurements of the calibration standards.

The Epsilon 1 ULS used in this study was calibrated with a set of sulfur in isooctane and a set of sulfur in diesel standards, with concentrations of sulfur at 0, 5, 10, 15, 25, 50 and 100 mg/kg, respectively.

The instrument's sensitivity was tested by calculating the peak/background ratio using the blank and 10 ppm sulfur standards. Despite the lack of helium to boost the detector's sensitivity, the Epsilon 1 ULS performed at least three times better than the norm required, showing that it is approximately three times as sensitive as it needs to be in order to comply.

In measuring the full range of sulfur concentrations, the instrument displayed a very high level of detail. Each of the concentration standards was clearly

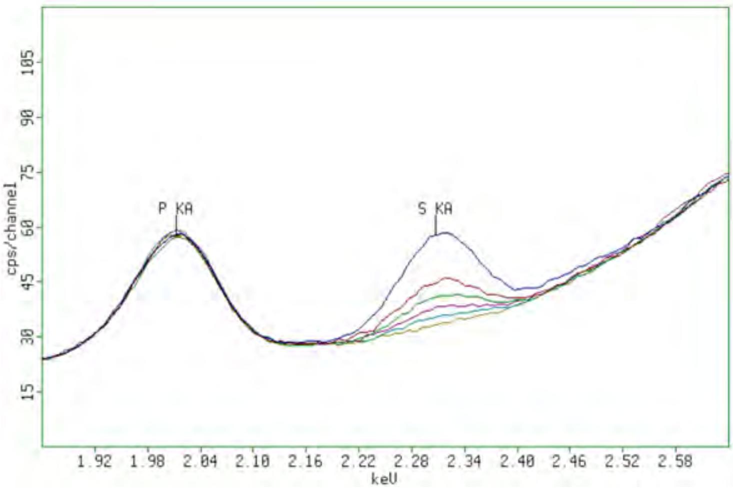

Figure 2. Results of X-ray spectra from the analysis of sulfur content at 0, 5, 10, 15, 25, 50 and 100 mg/kg.

differentiated, as can be seen in Figure 2. Even at the lowest ppm concentrations, the varying levels of sulfur are clearly visible in the data.

Working with spot crudes

As oil prices fluctuate, many companies need to work with purchase spot crudes in order to keep costs low. However, one well-known problem is that spot crude often contains more chlorine – a contaminant that needs to be tightly controlled. In the past, it has often been a challenge to measure chlorine alongside sulfur levels, because the quantities are radically different. However, it was found that the Epsilon 1 ULS was able to measure chlorine at ppm levels next to sulfur at percentage levels, avoiding extra testing.

Closing the gap

Malvern Panalytical decided to compare EDXRF against WDXRF to see how far apart the two methods are in terms of the lower limit of detection (LLD), using the company's Zetium 2.4 kW and testing both instruments on 20 measurements of 10 ppm of sulfur in diesel. It was found that there was only 0.2 ppm difference between the two methods – an impressive result given that no helium was used.

These results make it clear that EDXRF can reach the sensitivity needed to comply with ISO 13032 standards – and, most likely, with its successor – without helium. But how applicable is this to the real world? If the instrument is placed in a busy production process with relatively high throughput, it needs to be both reliable and consistent. The repeatability of these results is key to ensuring that this next-generation form of EDXRF is useful to the modern industry.

Real-world repeatability

In terms of repeatability (r), the ISO 13032 norm states that the difference between two test results obtained by the same operator with the same apparatus under constant operating conditions on identical test material is expected – in the normal and correct operation of the test method – to exceed at maximum the absolute value in equation 3, in the long run. This is only true for 1 case in 20, where X is the average of the two results in mg/kg:

$$r = 0.005X + 1.07 \qquad (3)$$

According to equation 3, the difference between two test results for sulfur at 10 mg/kg should be 1.1 mg/kg, with an exception of 1 in 20 permitted. In other words, 95% of the measurements should fall into this range. To test this, Malvern Panalytical repeatedly measured a freshly prepared 10 mg/kg sample of sulfur in a diesel sample for each measurement, and the first 33 measurements complied with the norm – without any exclusion. Going up to 39 measurements saw a difference smaller than 1.1 mg/kg between minimum and maximum, with just one exception. The standard deviation of the first 33 measurements was 0.3.

According to equation 2, the relative standard deviation based on 10 individual measurements of calibration standards should be smaller than 5%. So, for a standard of 10 ppm, the standard deviation should be smaller than 0.5 ppm. Malvern Panalytical decided to test many more times than 10 to ensure that the results were more representative and reliable. Throughout 57 measurements, the standard deviation over a period of 12 days was 0.49 ppm, implying that the instrument complies with the norm.

Calibration to stay on track

The instrument's calibration also needs to be validated regularly using blank oil samples in order to comply, so this was tested 59 times. The results of the blank samples should be 0 +/- 1 mg/kg, and for a sample containing 10 mg/kg sulfur the results should fall into the 10 +/- 1 mg/kg range – i.e., between 9 and 11 mg/kg. It was found that 57 of the 59 measurements fall into this range, again implying that it is possible to comply with the current norm using the Epsilon 1 ULS. However, in the long-term, regular drift correction needs to be carried out to ensure accurate data.

Looking ahead with confidence

Although a positive change, ISO 13032's update comes at a time of uncertainty for all industries, with economic pressures and ambitious sustainability goals leaving many companies juggling responsibilities. However, the greater control offered by the more sensitive instruments of today offers a number of possibilities in efficiency and process control – both of which are key to meeting these sustainability targets. The Epsilon 1 ULS is an example of the type of instruments that are likely to be seen across the industry in the future, as norms and technology continue to evolve before 2050.

PUMPS, VALVES & TURBOMACHINERY Q&A

Hydrocarbon Engineering sits down with a number of leading companies that specialise in pumps, valves and turbomachinery.

Mathieu Dorez, Valve Solution Engineer, Masoneilan Control Valves – Baker Hughes

Mathieu Dorez has 15 years' experience in control valves application engineering and technical sales, especially in engineered products for the oil and gas and power industries. He holds an Associate Degree in Mechanical Engineering from IUT Amiens, France, and an Engineering Degree in Mechanical Engineering from Conservatoire National des Arts et Métiers, Paris, France.

Rémi Lecomte, Product Manager, Cryostar

Rémi has 17 years' experience at Cryostar, starting his career as an API 617 Turboexpander Application Engineer. Later, Rémi managed the Application Team, before moving to sales as Key Account Manager. Since 2020, Rémi has been a Product Manager in charge of Cryostar's product portfolio for turboexpanders and cryogenic pumps. Rémi is also Cryostar's representative on the API 617 committee, and Lean Six Sigma Green Belt. In 2006, Rémi graduated from ISAE-ENSMA, Poitiers, France, with a degree in Mechanical Engineering.

Dominic Sarachine, Product Manager, Engineered and Air Separation, FS-Elliott

Dominic Sarachine graduated with a BS in Mechanical Engineering from Pennsylvania State University, US, and an MS in Mechanical Engineering from the University of Pittsburgh, US. He joined the FS-Elliott team in 2018. As the Product Manager of Engineered and Air Separation, he is responsible for developing a strategic vision for FS-Elliott's products to meet market demand in these segments, including centrifugal compressor products that support emerging markets as a result of decarbonisation.

Philippe Allienne, Industry Expansion Manager, Greene Tweed

Over his 27-year career at Greene Tweed, Philippe has held various strategic marketing roles, primarily focusing on pumps, mechanical seals, valves and turbomachinery for hydrocarbon processing, chemical processing, and power generation industries. For the last two years, Philippe has been responsible for business development for a portfolio of innovative material solutions targeted at the hydrogen and CCUS markets.

How have advancements in digitalisation impacted the pump, valve and/or turbomachinery sector?

Dorez, Baker Hughes: Digitalisation has revolutionised the way that equipment and systems are designed, operated, and maintained. Even though we have seen digitalisation since the 1990s, there is currently a real acceleration with cloud-based data storage and artificial intelligence (AI).

Advancements in digitalisation have brought numerous benefits to the pump, valve and turbomachinery sector, including improved design processes, enhanced operational efficiency, predictive maintenance, better energy management, and increased safety. Embracing digital technologies continues to be a key strategy for companies in this industry to stay competitive, optimise performance, and meet the demands of a rapidly evolving landscape.

Lecomte, Cryostar: I see two fields where digitalisation is playing an important role. The first one is obviously turbomachinery design, where computational tools (CFD, FEA, etc.) are already well established. We can also see this shifting towards manufacturing, where 3D printing is taking hold, opening up new manufacturing concepts and possibilities.

The second field is customer service, with the development of customer relationship management (CRM) tools. We can now easily manage our fleet of machines, and offer better service to our customers. Also, remote monitoring and diagnosis tools are developing quickly, opening the door to predictive maintenance, which is a very exciting subject, combining artificial intelligence (AI) and good old fashioned mechanics.

Sarachine, FS-Elliott: Perhaps the most lucrative area for owners and operators to focus on is the digitalisation of compressor controls. Far beyond simple energy monitoring, new algorithms and advanced graphics allow for control systems to suggest alternative control strategies and modes of operation calculated against actual operating history. These new control technologies will allow for more efficient operation of the machinery, resulting in lower operating costs and overall emissions. In addition, the modernisation of centrifugal compressors delivers greater efficiency and resilience. An important contributor to future-proofing the business, mechanical re-rating and upgrading control systems is easily justified by the savings made to operational costs, bridging the funding gap, and including plant and instrument air compressors in plant-wide digital transformation projects. Finally, there has been a great deal of improvement in the digitalisation of documentation and equipment data to make this information more readily accessible and available. One example of this is the use of SmartPlant data sheets that can be integrated with instrumentation diagrams and 3D models so that all key data can be accessed from a single source.

Talk us through a recent challenging project that you have worked on.

Lecomte: Cryostar was the first company to design a cryogenic vertical pump (VP) for the air separation unit market, back in the 1990s, and we have sold more than 2500 since then, making it our largest success.

After 30 years of service, we decided to launch our NeoVP, with the aim of greatly improving pump performance and maintainability without, of course, compromising safety.

The NeoVP programme is now almost complete, with the first pumps recently put into operation successfully.

There were many challenges during the development of the programme, but the most challenging phase was industrialisation. As engineers, we tend to focus on design and we take manufacturing for granted. However, when introducing optimised parts, especially after 30 years and thousands of references, we also introduce new challenges to our manufacturers. My advice is to include your manufacturers early in the review of your new design, and build prototypes where needed, so that you can solve the issues early in the process.

Allienne, Greene Tweed: Hydrogen is a very challenging molecule, and its interaction with materials such as polymers and elastomers is not well understood today. As a provider of high-performance materials, it is critical to generate test data that enables us to better understand material behaviour in various environments of hydrogen applications. Because interest in hydrogen is still recent, a global and uniform industry standard applicable for various equipment that can determine material compatibility with hydrogen is not yet settled. To overcome the challenge of finding a suitable testing procedure for materials in hydrogen service, we conducted intense global research and identified an advanced research programme led by two major national labs and sponsored by the US Department of Energy (DOE), where we tested several of our materials under severe test conditions, with promising results.

What role will turbomachinery, pumps and/or valves play in supporting the hydrogen economy?

Dorez: Hydrogen is being considered as a clean energy carrier and a potential solution for decarbonisation in various sectors. Turbomachinery, pumps and valves are used in various methods of hydrogen production. For example, in steam methane reforming (SMR), pumps and valves are employed to handle the feedstock and control the flow of reactants. Turbomachinery, such as compressors, are used for the compression of the process gases. In electrolysis, pumps are used to supply water to the electrolyser, and valves control the flow of water and gases within the system. Turbomachinery, such as compressors and turbines, can be involved in hydrogen compression and power generation for the electrolysis process.

Pumps and valves are also essential for the storage and transportation of hydrogen. Pumps are used for the

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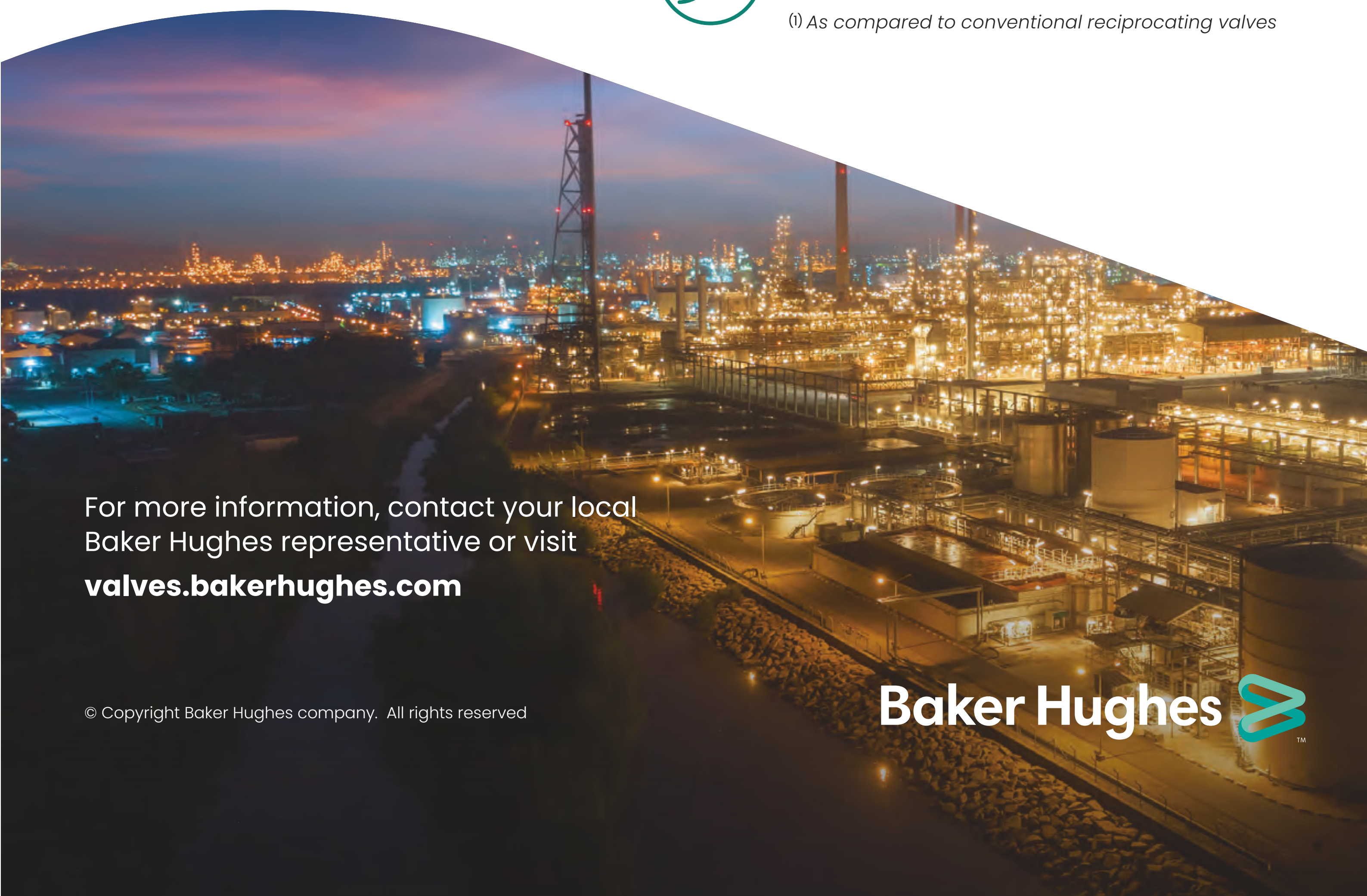

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compression and transfer of gaseous hydrogen, while valves regulate the flow and control the pressure in storage tanks and pipelines. Additionally, turbomachinery can be used in hydrogen compression for transportation purposes.

Turbomachinery also plays a role in hydrogen conversion and utilisation processes. For example, in fuel cells, which convert hydrogen into electricity, turbomachinery can be used for air compression and oxygen supply. Pumps and valves are also utilised in various applications, such as hydrogen refuelling systems for fuel cell vehicles, or in industrial processes that utilise hydrogen as a feedstock.

Lecomte: Turbomachinery and pumps are probably the biggest challenge in the hydrogen economy.

Before using hydrogen, it is necessary to store it, which requires either compression at very high pressures of 350 bar or even 700 bar, or liquefaction at ultra-low temperatures of around 20 K.

Given its low density, hydrogen requires very high peripheral speed in turbomachinery, thus causing very high stresses. Material compatibility with hydrogen also limits the available options. Therefore, turbomachinery and pumps for hydrogen require a rotor with excellent mechanical resistance/mass ratio, that is compatible with hydrogen.

Last but not least, hydrogen tightness and fugitive emissions will be an important subject for turbomachinery and valve packing.

What has been your company's biggest recent achievement or innovation?

Allienne: In keeping with Greene Tweed's tradition of solving our customers' toughest challenges and leveraging our expertise in both product design and polymer science, we developed the world's first commercially-available cross-linked PEEK thermoplastic. Arlon 3000 XT® was initially developed to improve PEEK's mechanical properties, such as tensile strength, creep, and modulus, for ever more severe high-pressure, high-temperature oilfield downhole applications such as seals, valve seats, and electrical connectors. It has since been used to extend the performance envelope, lifetime, and reliability of a variety of applications where PEEK or other extreme-performance plastics may not be sufficient. Recent testing has shown excellent high-temperature dielectric properties, enhanced creep resistance at moderate temperatures, and high elongation under cryogenic conditions, making it ideal for many hydrocarbon processing and hydrogen applications.

What is your company's R&D process for emerging designs?

Lecomte: Cryostar has a process to manage a R&D project, from feasibility to prototype testing and industrialisation.

However, there is no rigid process concerning design and ideas, as this would most probably reduce our creativity.

Also, I believe it is important not to restrict improvements and ideas to new designs. Improvements can be integrated into our commercial products gradually, improving them step-by-step, and not waiting for the launch of a major R&D project. It also keeps the operational team motivated, without unnecessarily placing pressure on the R&D department.

Finally, a multidisciplinary approach should always be encouraged. R&D projects should involve manufacturing, procurement and industrialisation – not only engineering.

Talk us through your company's approach to equipment reliability and maintenance.

Sarachine: Since 1962, FS-Elliott has been one of the world's leading manufacturers of integrally-geared, centrifugal air and inert gas compressors. The company was a major contributor to the establishment and development of API 672 and continues to contribute to this globally accepted compressor standard, now in its fifth edition. With many of FS-Elliott's earliest designs still in operation today, a company spokesperson said: "Getting it right the first time has been the key to our success, and we've stayed on that same path. Our ability to support machines that are three times their original design life expectancy makes for strong relationships in this business."

Allienne: At Greene Tweed, we are committed to developing materials and solutions that improve the reliability of critical equipment, including compressors, pumps, and valves. Take our composite parts, for instance. Customers who upgrade to composite wear parts from metal wear parts in their pumps experience reliability improvements and report improved mean time between repairs (MTBR), minimised chance of catastrophic damage, reduced vibration, improved efficiency, and reduced total cost of ownership for the equipment.

Talk us through the importance of monitoring vibration and other critical machine considerations.

Sarachine: Vibration monitoring is critical to the safe operation of machinery, as even the smallest increase in vibration levels can result in costly damage to the machinery or even potential injury to operators. As a result, vibration is a critical monitoring point for most machinery, resulting in alarms or even automatic tripping of the equipment to avoid damage or injury. Additionally, tracking process operating temperatures and pressures allows for more proactive equipment monitoring. Using the latest control systems, including remote monitoring, the equipment can be controlled

and monitored remotely from anywhere. The most current control systems can also provide more proactive notifications for maintenance using multiple data points to avoid costly unplanned shutdowns.

Allienne: Greene Tweed's materials are inherently non-galling and non-seizing. As a result, they can operate effectively with reduced clearances compared to metallic components. Closer clearances between the shaft and stationary wear rings result in higher bearing pressure, leading to lower vibration and improved reliability, as well as reduced recirculation and increased efficiency.

We advise users to find the right material solutions to maximise their equipment efficiency.

How can pumps, valves and/or turbomachinery be integrated into carbon capture plants?

Dorez: Pumps, valves and turbomachinery play integral roles in carbon capture plants, which are designed to capture and store or utilise carbon dioxide (CO_2) emissions from industrial processes.

Pumps are used to transfer fluids within carbon capture plants. They facilitate the movement of various process streams, including the transport of flue gas from the industrial source to the carbon capture unit. Pumps are also employed for the circulation of solvents or absorbents used in the CO_2 capture process, such as amine solutions. These pumps must be capable of handling corrosive and high-temperature fluids.

Valves are critical for controlling the flow of fluids and directing them to different process units within the carbon capture plant. They are used to regulate the flow of flue gas, solvents, and other process streams. Valves are necessary for diverting the flue gas to the absorption column, controlling the solvent flow rate, and directing the flow of CO_2-rich solvents for further processing.

Once the CO_2 is captured, it needs to be compressed for transportation and storage. Compressors, such as reciprocating compressors or centrifugal compressors, are used to increase the pressure of CO_2 to the desired levels for storage or utilisation. These compressors are designed to handle the specific properties of CO_2, ensuring efficient and reliable compression.

Integration of pumps, valves and turbomachinery into carbon capture plants is essential to enable the efficient capture, compression and transport of CO_2 for storage or utilisation. These components work together to ensure the effective operation of the carbon capture process, contributing to the reduction of greenhouse gas emissions and the advancement of sustainable practices.

Allienne: Every step of the carbon capture, transportation, storage, and utilisation process requires the use of pumps, valves and compressors. Just like hydrogen, they require special attention and should be adapted to the specific needs of carbon dioxide (CO_2) molecules. For example, rapid gas decompression (RGD) could represent a major problem in supercritical CO_2 applications, primarily in the transportation phase. Special elastomers are required in equipment such as valves, compressors or pigs found in these applications. Similarly, non-galling and non-seizing materials such as PEEK composites should be considered for pump wear parts in compression or injection applications due to the very low lubricity of supercritical CO_2.

What advice do you have to maximise pump, valve and/or turbomachinery efficiency?

Dorez: To maximise the efficiency of pumps, valves and turbomachinery, here are some key pieces of advice. Firstly, it is important to select the right equipment. It should be properly sized and designed for the specific application. Consider factors such as flow rates, pressure requirements, temperature range, and fluid properties.

It is also important to pay attention to the overall system design and layout. Minimise pipe lengths, bends and restrictions that can cause pressure losses and inefficiencies. Optimise pipe sizes to reduce friction losses and ensure smooth flow. Properly size and locate valves to avoid excessive pressure drops.

Establishing a routine maintenance and inspection schedule is also advisable. Regularly check for leaks, wear, and signs of degradation. Keep equipment clean and free from debris. Follow manufacturer guidelines for maintenance procedures and lubrication to ensure optimal performance.

I would also advise you to implement real-time monitoring systems to continuously monitor operating conditions such as pressure, temperature, vibration, and flow rates. This allows for early detection of abnormalities or deviations from optimal operating parameters, enabling proactive maintenance and the ability to address potential issues before they escalate.

Use advanced control systems and automation technologies to optimise the operation of pumps, valves and turbomachinery. Implement intelligent control algorithms that adjust equipment operation based on real-time conditions and demands. This helps to ensure that the equipment operates at its most efficient points, and minimises energy waste.

Explore opportunities for energy recovery within the system. For example, consider using waste heat from pumps or turbomachinery for other processes or heating purposes. Implement energy-efficient motors and variable speed drives to match energy consumption with demand, and avoid unnecessary energy losses.

It is also advisable to conduct regular performance evaluations. Measure and analyse energy consumption, efficiency and output. Identify areas for improvement and implement optimisation measures based on the findings.

Invest in training and expertise for operators and maintenance personnel. Ensure that they have a deep

understanding of the equipment, its operation, and maintenance requirements. Properly trained personnel can identify and address issues promptly, optimising efficiency and minimising downtime.

Finally, stay informed about technology advancements. Periodically assess whether upgrades or newer technologies can improve efficiency and performance. Consider adopting innovations such as advanced materials, improved designs, or smart monitoring systems to enhance overall efficiency.

Lecomte: We tend to focus on peak efficiency, but we often find that turbomachinery and pumps are operated off-design. Therefore, my advice would be to broaden the peak efficiency region, rather than maximising it on a narrow area.

Also, our turbomachinery and pump designs have to last many years. Therefore, it is important to anticipate future driver capacities and optimise machines at the right speed.

Finally, never trade efficiency for reduced reliability. An efficient pump or turbomachinery is first a machine that is running flawlessly.

Sarachine: To maximise efficiency, proper site and design conditions should be considered closely in order to properly size the equipment. If conditions such as temperature, pressure, or relative humidity are not accurate, the machinery may not operate efficiently, resulting in higher capital and operating costs. Many customers may choose to size equipment for a worst-case condition or a combination of worst-case conditions that may not be realistic or only occur a few times a year. Designing the equipment specifically for this worst-case condition as opposed to the typical site conditions may result in oversized and inefficient equipment. In addition to higher costs, this inefficiency will result in increased power consumption and higher overall emissions.

Where do you see the pumps, valves and/or turbomachinery market 10 years from now?

Dorez: Over the past decade, the pumps, valves and turbomachinery market has witnessed significant advancements driven by various factors such as industrial growth, infrastructure development, and technological innovations. These components play a crucial role in industries such as oil and gas, power generation, water and wastewater treatment, chemical processing, and many others.

Considering the ongoing trends and potential future developments, here are a few possibilities for the pumps, valves and turbomachinery market in the next decade:

The market is likely to see continuous advancements in technology, leading to the development of more efficient, reliable and intelligent pumps, valves and turbomachinery. This could include the integration of sensors, automation, and data analytics to optimise performance, reduce energy consumption, and enhance predictive maintenance capabilities.

With growing concerns about energy consumption and environmental sustainability, there will likely be a greater emphasis on energy-efficient solutions. Manufacturers may focus on designing and producing equipment that minimises energy wastage and reduces carbon footprints, aligning with global efforts towards sustainable development.

As the world shifts towards cleaner and renewable energy sources, such as wind, solar, and hydroelectric power, the demand for specialised pumps, valves and turbomachinery in these sectors is expected to increase. This could drive innovation and create new market opportunities for manufacturers.

The adoption of automation and digital technologies in industries is expected to continue its upward trajectory. The integration of pumps, valves and turbomachinery with smart systems, Industrial Internet of Things (IIoT), and cloud computing can enable real-time monitoring, remote operation, and predictive maintenance, leading to improved efficiency and productivity.

Developing economies, particularly in Asia, Africa and Latin America, are witnessing rapid industrialisation and infrastructure development. This growth is likely to contribute to increased demand for pumps, valves and turbomachinery in sectors such as water management, construction, and manufacturing.

The industry may face challenges related to stringent environmental regulations, safety standards, and cybersecurity concerns. Manufacturers will need to address these challenges by developing compliant and secure solutions, thereby ensuring the reliability and integrity of pumps, valves, and turbomachinery.

It is important to note that these predictions are speculative, and the actual market developments may vary. The future of the pumps, valves and turbomachinery market will depend on a complex interplay of various factors, including economic conditions, technological breakthroughs, regulatory changes, and global trends in energy and industry.

Sarachine: Collectively, indications are that the market will be healthy in terms of its size and competition for business. Decarbonisation and resulting technological advancements will play an important part in creating opportunities for new and existing key players to fill the supply gap. Although there are indications that investment in greenfield oil and gas refineries will decrease, the opportunities for carbon capture and other decarbonisation technologies will allow for additional growth within the turbomachinery market as new and existing plants will require additional equipment to meet carbon dioxide (CO_2) emissions goals.

SELECTING RELIABLE PUMPS

Nicki Teumer, LEWA GmbH, Germany, details a specific case study whereby the company replaced pumps within a German refinery's distillation unit, after they were damaged.

As a result of an incident at an oil refinery in 2020, in Salzbergen, the Emsland region of Germany, several pumps in the distillation unit – among other equipment – were severely damaged. The refinery in question was founded in 1860, and is one of the oldest specialised refineries in the world that is still in production today. In addition to paraffins and waxes for specific industrial

Figure 1. The refinery in Salzbergen, Germany (source: H&R KGaA).

applications, the refinery manufactures products for the cosmetics and pharmaceutical industries; the mineral oil trade; and the construction industry.

In order to be able to resume production as quickly as possible, the refinery's operator, H&R ChemPharm GmbH, decided to quickly purchase replacement units. As Nikkiso pumps from LEWA GmbH had already been successfully used for conveying the distillates that were produced at the plant, the company's leakage-free non-seal canned motor pumps were selected for use once again.

This article will discuss the company's purchase of two of LEWA's pumps, and detail the benefit of these pumps to plant operations.

Figure 2. Leakage-free, non-seal canned motor pumps from LEWA GmbH (source: H&R KGaA).

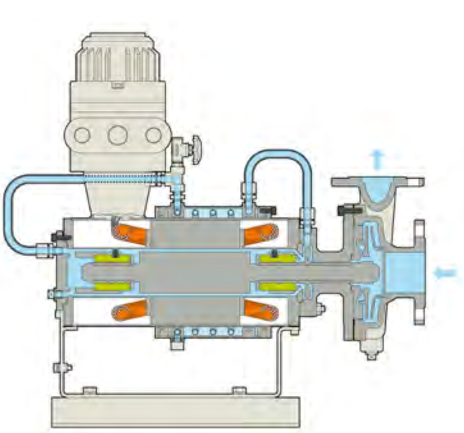

Figure 3. Non-seal HT pump (source: LEWA GmbH).

Protecting the environment and personnel

The refinery's choice fell on four non-seal pumps consisting of two essential components: a centrifugal pump and an air-tight canned motor, which share a common shaft to form a single unit. As the motor is inside the flame-proof stator housing, the result is an encapsulated and completely leakage-free design that enables a dynamic seal-free pump construction. The double safety shell minimises both immediate and long-term hazardous risks for employees and the environment as, even if a can is damaged, it prevents both product losses and the release of harmful emissions into the atmosphere. Thus, operating personnel are protected from contact with harmful substances, and even explosive, flammable and aggressive fluids can be handled without any problems. The absence of dynamic seals, which are usually costly and repair-intensive, increases mean time between failure values, which also contributes to plant safety.

The bearings used are slide bushings, which can be made of different materials depending on the properties of the conveyed medium. The bearing material range includes various carbon graphite grades, polytetrafluoroethylene (PTFE) and silicon carbide, and a mixed composition of carbon and silicon carbide that ensures protection against wear. A graphite mixture is used in the pumps at the refinery in Salzbergen. The bearings are lubricated by the handled fluid itself, which is also used to cool the motor. Depending on the pump design and medium, a maximum conveyance rate of up to 1200 m^3/hr can be attained, with fluid temperatures of between -200 – 450 °C. The pumps can also be designed in accordance with API 685, and certified for up to 350°C in accordance with ATEX 2014/34/EU. This was also the case with the models for H&R ChemPharm, so that they meet the high requirements and loads in refineries, as well as the chemical and petrochemical industry.

Units designed for hot liquids and slurry

For conveying the distillate at the refinery in Salzbergen, two HT pumps with external motor cooling – which were specially designed for hot media – were selected. In this model, the process liquid is circulated inside the rotor chamber via an auxiliary impeller.
In order to maintain a suitable fluid temperature in the rotor chamber, a cooling jacket is provided together with a spiral tube heat exchanger and a thermal insulation spacer. Units of this type achieve a flow rate of up to 780 m^3/hr, a head of up to 210 m, and a maximum motor output of 200 kW. They can be used for media with a viscosity of ≤ 200 centipoise (cP) and temperatures of up to 450°C.

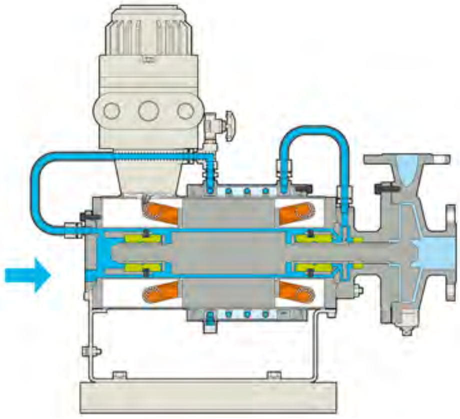

Figure 4. Non-seal HS pump (source: LEWA GmbH).

The 324°C medium handled in Salzbergen does not pose any problem. As with the other models in the series, the units are characterised by absolute tightness, a high level of smoothness, and long service life. This also applies to the two non-seal HS pumps that were part of the purchase. These feature backflushing and are therefore particularly suitable for liquids containing solids. The units reliably convey media with a viscosity of up to 500 cP, and their head is up to 210 m. Both pumps were also equipped with external motor cooling for hot media, for use at H&R ChemPharm's facility.

All four pumps have an e-monitor. This monitoring system enables permanent control of the bearing conditions of leakage-free pumps, and is a prerequisite for highly-reliable operation. Sensors integrated into the stator determine the radial and axial position of the rotor assembly during operation, for this purpose. If, for example, bearing wear occurs, the corresponding sensors register this exceptional situation immediately. This is indicated on a display using a traffic signal system so that measures for maintenance can be scheduled systematically.

Conclusion

Another decisive factor behind the order that was placed for the refinery in question was that the Nikkiso non-seal canned motor pumps could be delivered as quickly as possible. LEWA submitted a bid with the shortest delivery time that was feasible for H&R ChemPharm – just one day after the defective pumps were identified, which was one week after the incident at the refinery – and was awarded the contract in September 2020. The pumps were delivered to the Salzbergen refinery as planned, at the end of January 2021, and have been in operation since February of that year. The delivery dates were met and the entire cooperation with LEWA on this project was a success. The pumps continue to run to the company's complete satisfaction.

BAD VIBRATIONS

Marwan Karaki, Weir Minerals, discusses the complications associated with mechanical and hydraulic vibrations in vertical chemical pumps, which are used to transfer molten sulfur, sulfuric acid and phosphoric acid within plants.

There are many benefits to using a vertical pump to transfer molten sulfur, sulfuric acid and phosphoric acid. These types of pumps promote a safer operational environment, as the vertical design eliminates pressurised seal area concerns and the pumped fluid never touches the shaft stuffing box.

However, there are certain considerations behind choosing a vertical chemical pump. To better understand the issues and concerns with vertical chemical pumps, it is important to explore common concerns of the pump system. While each company extensively tests their pumps prior to shipment, many factors can affect the effectiveness of the pump. Such factors may include the type of fluid being pumped, temperature of the fluid, pump speed, operation schedule, and maintenance/turnaround schedules.

Regardless of the industry, vertical chemical pumps may experience complications as a result of unintentional vibration. The most common causes of pump vibration can be categorised as either mechanical or hydraulic. This article will explore these two types of vibrations and their potential causes.

Mechanical vibration

Pump alignment

It is very important that all critical pump components are aligned properly, particularly the shaft column, discharge pipe, and volute. Before installing a pump and after all pump maintenance, a freedom of rotation test should be performed by suspending the pump vertically, and manually turning the shaft to determine whether any interference exists. After installation, the forces and moments at the flanged connections should be maintained within allowable margins to eliminate distortions that may cause rubbing of rotating parts where clearances are reduced or even eliminated.

Shaft straightness

The pump shaft must be maintained as straight as possible at all times. Straightness must be checked at major overhauls or when the shaft assembly is rebuilt, even if there is no vibration. When mounted between centres in a lathe, the run-out at critical points – such as the mid-point of shaft bearing assemblies and the impeller location – should be within 0.002 in. total indicator runout (TIR). Vibration frequency owing to the degree of shaft straightness ranges from one-time rotational speed to occasionally two to three times rotational speed. The amplitude is typically 150% of radial vibration in the axial plane.

Unbalanced impeller

The impeller is a major rotating mass in the pump that, if unbalanced, may result in high vibration. All Weir Minerals' Lewis® impellers are dynamically-balanced to ISO standard 1940/I Grade 6.3 or better, depending on customer specifications.

Impellers in both sulfur and acid environments may face rough conditions that lead to impeller imbalance. In sulfur environments, a foreign object might hit the impeller at high speed, resulting in damage that causes imbalance. In an acid environment, an impeller may suffer from uneven areas of erosion or corrosion that result in imbalance and significant pump vibration. Selecting the appropriate material is critical in order to avoid such situations. In general, the vibration frequency in this instance is equal to the rotational speed. Amplitude is greatest in the radial direction with a magnitude that is proportional to the amount of imbalance.

Bearing lubrication

The majority of Lewis vertical chemical pumps are supplied with a shielded, double-row ball bearing of maximum capacity design, intended to handle the applied hydraulic and mechanical loads properly. It is important to have the bearings replaced with original equipment manufacturer (OEM) parts and to rigorously follow the pump manufacturer's lubrication instructions. Proper installation of the bearing to both the shaft and the ball bearing housing is critical. The vibration frequency related to bearings is equal to the rotational speed times the number of rolling elements, and amplitude is proportional to the damage and wear of the bearing. In addition, it is well known that amplitude increases with time.

Figure 1. Cavitation damage to an impeller.

Motor/driver

The motor/driver may generate some vibration caused by a worn bearing or an imbalanced rotor. If supplying your own motor, it is recommended to run the motor isolated from the pump to determine whether there is any vibration caused by the motor. If the motor is new, requesting a routine test that will lead to testing and certification by the motor manufacturer is highly recommended.

Base plates

Vertical pump cover plates and sole plates should be levelled and sufficiently robust. The components should be carefully examined after several years of service, as they have the tendency to lose their rigidity and distort, contributing to major pump vibration. Misaligned plates prevent the pump from being properly rebuilt and aligned.

Pump motor alignment

In some cases, abnormal vibration and mechanical performance can be derived from poor alignment between the pump and the motor. The misalignment of the coupling has no direct effect on the motor efficiency; however, correct alignment will ensure a smooth, efficient transmission of power from the motor to the pump. Misalignment takes place when the centre lines of the pump and the pump shaft are not in line with each other. Misalignment can cause the following symptoms: excessive vibration, increased bearing temperature, and shortened bearing or coupling life.

There are three types of misalignments to look for:

- Angular misalignment occurs where the motor is set at an angle to the pump. If both shafts are extended, they will cross each other.
- Parallel misalignment occurs where the motor and pump shafts are parallel to each other.
- Combination misalignment occurs where the pump and motor shaft suffer from an angular and parallel misalignment.

Hydraulic vibration

Cavitation

Cavitation occurs when the Net Positive Suction Head Required (NPSHr) is greater than the Net Positive Suction Head Available (NPSHa). This causes an implosion of vapour bubbles formed in the liquid being pumped, usually on the low-pressure side of the impeller vanes. Cavitation can result in damage to the impeller by removing particles of


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metal from the surface with explosive force. This causes several problems, including discernible pump vibration. Most of the time, this condition takes place when there is a change in the system characteristics that alter the pump flow and head conditions for which the pump was originally selected.

Hydraulic imbalance

Suction conditions may exist that cause the flow distribution of liquid entering the pump impeller to be uneven. This can result from vortexing, improper clearances under or around the pump's suction inlet, or gas entrainment. The effect can be much the same as cavitation due to insufficient NPSHa.

Vibration monitoring

Vibration monitoring is fairly common today. Accelerometer probes are usually installed on the pump's upper thrust bearing or on a motor bearing. Measurements in at least two horizontal planes, located 90° apart, and in the vertical plane, can be made for vibration amplitude and frequency.

A log of these readings can be useful in both helping to discern the beginning of component wear before failure, and in identifying and remedying an installation problem. It is perhaps less important to focus on the magnitude and exact frequency of vibration (unless it is extreme) than it is to pay attention to a change in the signature or pattern of the vibration spectrum. However, it is important to be aware that it is nearly impossible to completely eliminate all pump installation vibration.

ANSI/HI-9.6.4-2001 edition, Centrifugal and Vertical Pumps, Vibration Measurement and Allowable Values, provides a guideline for the acceptable level of vibration depending on the pump structure. However, with knowledge of vibration sources, a good maintenance programme and installation procedures, and perhaps a monitoring system, pump vibration can be controlled, and serious problems can be avoided.

Conclusion

While vertical chemical pumps are an excellent choice for transferring molten sulfur, sulfuric acid and phosphoric acid, important considerations should be made before choosing a vertical chemical pump. Unintentional mechanical or hydraulic vibrations may result in complications and affect the pump's effectiveness. It is crucial to take preventative measures to ensure the proper alignment of critical pump components, maintain a straight shaft, have a balanced impeller, have OEM bearings with proper lubrication, and have good alignment between the motor and the pump.

Cavitation, a type of hydraulic vibration, can also occur when the NPSHr is greater than the NPHSa, leading to the implosion of vapour bubbles that can damage the pump's impeller. Therefore, proper pump selection, installation and maintenance are necessary to achieve the best performance and longevity of vertical chemical pumps. HE

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