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February 2024

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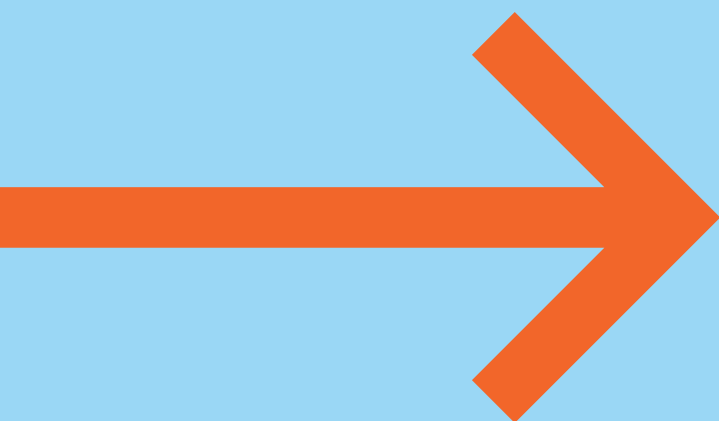
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# COMMENT

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**HYDROCARBON  
ENGINEERING**



## CALLUM O'REILLY SENIOR EDITOR

Which of Australia's international exports do you think was recently described as a "source of national pride" by the country's Treasurer, Jim Chalmers? "[Its] brilliance", Chalmers says, "is not just as an export but as a symbol of Australia. Nothing says Australia quite like *Bluey*."

For any readers with children (or grandchildren) under 7 years old, it's likely you will be familiar with *Bluey* – a television show about an animated family of four Australian cattle dogs. But for those of you who aren't, I say this: you're missing out. There is good reason why this Aussie animation has taken the world by storm and amassed record viewing figures (in the US, where it is streamed on Disney+, it was the most streamed show of any genre in early December 2023). Put simply, the show is a delight, for children and adults alike. It is thoughtful and funny and heart-warming in equal measure. If you have seven minutes to spare, I would highly recommend giving it a try (some of my personal favourite episodes include 'Flatpack', 'Octopus', 'Stumpfest' and 'Sleepytime').

However, as successful as *Bluey* has been as a cultural export, it has not been as lucrative as it could have been for Australia's national broadcaster, ABC. In 2017, the British Broadcasting Corp. (BBC) attained the broadcasting rights for the show globally (excluding Australia), as well as licensing and merchandising rights worldwide (including Australia). In the BBC's annual report last year, it was singled out as a significant factor in its 28% revenue increase to £2 billion.<sup>1</sup>

Another of Australia's successful – and more profitable – exports is LNG. However, the sector is coming under pressure. The country has been toppled as the world's top LNG exporter by the US, and the government's Department of Industry, Sciences and Resources expects exports to decline to 80 million t in 2023 - 2024 and 78 million t in 2024 - 2025, compared to 83 million t in 2021 - 2022. In turn, earnings from exports are forecast to fall from AU\$92 billion in 2022 - 2023 to AU\$73 billion in 2023 - 2024 and AU\$64 billion in 2024 - 2025.

The country's LNG sector faces growing fiscal, regulatory and legal pressures that producers worry could threaten investment. Last year, the President and CEO of INPEX, Takayuki Ueda, suggested that Australia is "quietly quitting" the LNG business, following increased government regulations.

There is also concern that LNG demand will be impacted by weakening economic prospects in some Asian countries, and increasing reliance on renewables. However, demand across Asia surged in the second half of 2023, with imports rising to a record 26.61 million t in December 2023 (largely driven by China).

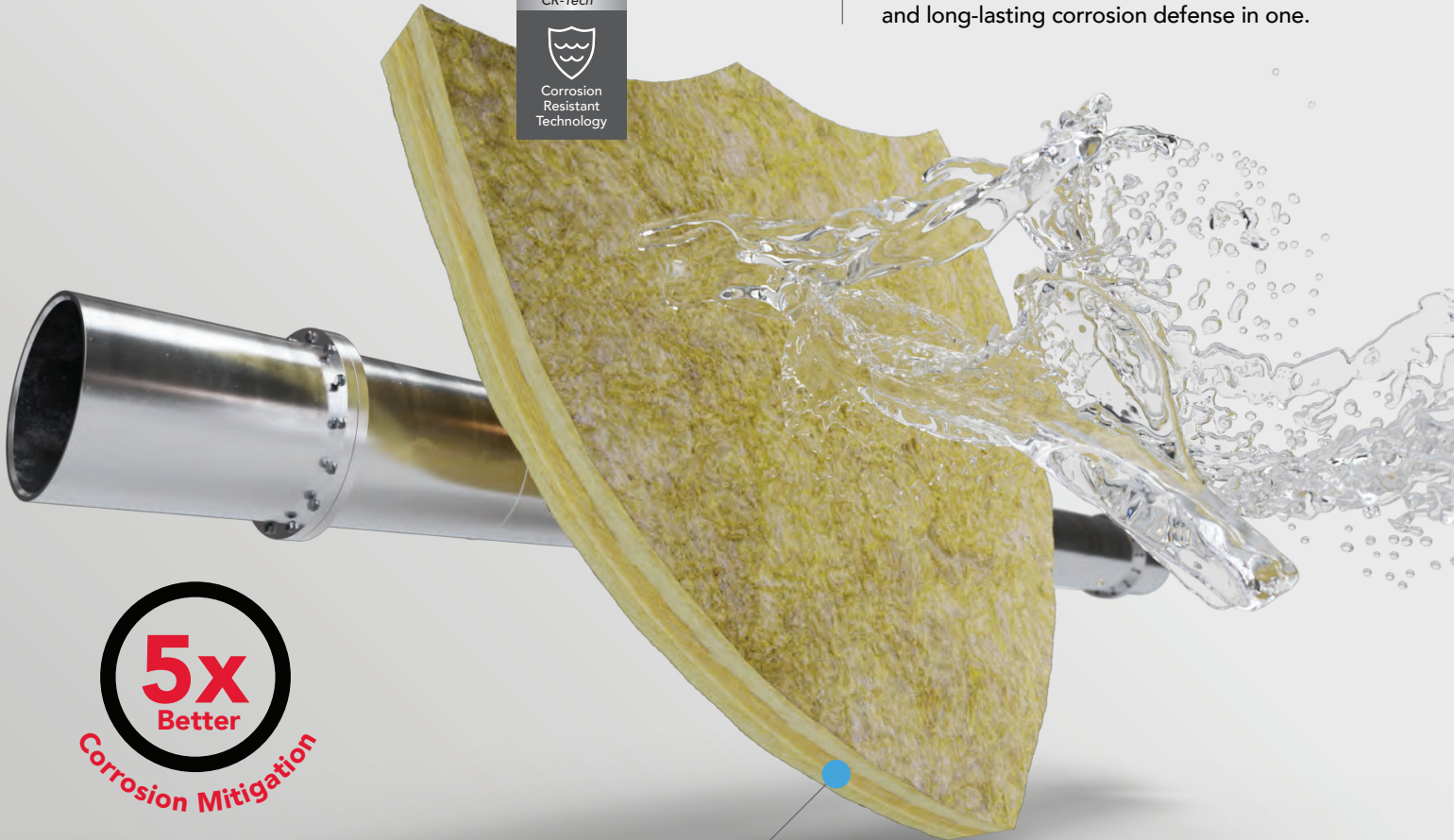
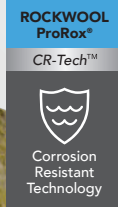
In this issue of *Hydrocarbon Engineering*, we take a forensic look at the country's downstream petroleum industry (as well as developments in its neighbouring Australasian countries). Starting on p. 8, Contributing Editor, Nancy Yamaguchi, discusses the wholesale retreat of Australasia's refining sector, the partial recovery in oil product demand, and the impacts on oil product trade.

1. FILDES, N., 'How Australia's 'Bluey' conquered children's entertainment', *Financial Times*, (1 January 2024).

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# WORLD NEWS

## UK | BP awards global framework agreement to Worley

BP has awarded a new five-year global framework agreement to Worley.

Under the agreement, Worley will provide engineering, procurement, and construction management (EPCM) services covering BP's global refinery assets and new energy portfolio including strategic projects in green and blue hydrogen, lower carbon fuels and sustainable aviation fuels (SAFs).

The services will be executed by Worley's offices globally with support from Global Integrated Delivery (GID) teams.

"We're pleased to be working with BP as a trusted partner on this framework agreement, which strengthens our longstanding relationship and will contribute to helping BP meet the world's changing energy needs," said Chris Ashton, CEO of Worley.

## India | HPCL awards CLG new licensing contract

Chevron Lummus Global LLC (CLG) has been awarded a new licensing contract by Hindustan Petroleum Corp. Ltd (HPCL) for the development of a grassroots integrated hydrocracker and catalytic dewaxing unit as well as a full catalyst reload of its existing lube oil upgrading programme (LOUP) at the Mumbai Refinery in India.

The integrated hydrocracker and catalytic dewaxing unit will have a nameplate capacity of 550 000 tpy and will facilitate the production of Gr. II+ and Gr. III premium base oils. This strategic move will enable HPCL to make a significant foray into the premium base oil market, tapping into new avenues for growth and market expansion.

## USA | Woodside and Rice University partner up

Rice University and Woodside Energy have announced a five-year technology collaboration aimed at reducing greenhouse gas emissions and providing lower carbon solutions.

Woodside will provide US\$12.5 million to fund the creation of the Woodside-Rice Decarbonisation Accelerator, an initiative that aims to bring breakthrough decarbonisation technology from the Rice labs to market.

"This collaboration is a testament to the power of merging academic expertise with industry insight and support. Together, we aspire to redefine the future of energy and climate," said Rice University President, Reginald DesRoches.

"Net zero is not a destination but a journey. Over the next 10 years, emerging and breakthrough technologies must come to market if society is to meet its climate goals," said Woodside CEO Meg O'Neill.

## Saudi Arabia | LyondellBasell to acquire 35% of NATPET

LyondellBasell has announced that it has entered into an agreement to acquire a 35% interest in Saudi Arabia-based National Petrochemical Industrial Co. (NATPET) from Alujain Corp. for approximately US\$500 million.

Enabled by its Spheripol polypropylene (PP) technology, the joint venture (JV) positions LyondellBasell to grow and upgrade its core PP business through access to advantaged feedstocks, plus additional product marketing capacity, in a strategic region.

Alujain and LyondellBasell are also assessing potential construction of a new propylene via propane dehydrogenation (PDH) and PP facility at the NATPET site, subject to final investment decision (FID). The project is being studied with a shared goal to implement solutions that align with Saudi Arabia's 2060 carbon reduction strategy.

Alujain is a petrochemicals, energy, mining and metals company. As majority owner of NATPET, the company is a longtime licensee of Spheripol PP technology, one of the

solutions it uses to operate a propylene and PP complex in Yanbu Industrial City. NATPET currently has an annual PP production capacity of approximately 400 000 tpy.

"This investment in NATPET reflects our strategy of growing and upgrading our core around assets and businesses with lasting advantages. We look forward to advancing our collective efforts to produce and market essential materials that serve our customers' needs across the globe," said LyondellBasell CEO, Peter Vanacker.



# WORLD NEWS

## DIARY DATES

03 - 07 March 2024

**AMPP Annual Conference + Expo**

New Orleans, Louisiana, USA  
[www.amp.org](http://www.amp.org)

10 - 12 March 2024

**AFPM Annual Meeting**

Grapevine, Texas, USA  
[www.afpm.org/events/AnnualMeeting2024](http://www.afpm.org/events/AnnualMeeting2024)

12 - 13 March 2024

**StocExpo**

Rotterdam, the Netherlands  
[www.stocexpo.com](http://www.stocexpo.com)

24 - 26 March 2024

**AFPM International Petrochemical Conference**

San Antonio, Texas, USA  
[www.afpm.org/events/IPC24](http://www.afpm.org/events/IPC24)

02 - 04 April 2024

**Sulphur World Symposium**

Charleston, South Carolina, USA  
[www.sulphurinstitute.org/symposium-2024](http://www.sulphurinstitute.org/symposium-2024)

29 April - 03 May 2024

**RefComm**

Galveston, Texas, USA  
[www.events.crugroup.com/refcomm](http://www.events.crugroup.com/refcomm)

14 - 16 May 2024

**Asia Turbomachinery & Pump Symposium**

Kuala Lumpur, Malaysia  
[atps.tamu.edu](http://atps.tamu.edu)

10 - 14 June 2024

**ACHEMA**

Frankfurt, Germany  
[www.achema.de/en](http://www.achema.de/en)

11 - 13 June 2024

**Global Energy Show**

Calgary, Alberta, Canada  
[www.globalenergyshow.com](http://www.globalenergyshow.com)

20 - 22 August 2024

**Turbomachinery & Pump Symposia**

Houston, Texas, USA  
[tps.tamu.edu](http://tps.tamu.edu)

17 - 20 September 2024

**Gastech**

Houston, Texas, USA  
[www.gastechevent.com](http://www.gastechevent.com)

### China | SABIC announces FID for Fujian petrochemical plant

SABIC has announced the final investment decision (FID) for the SABIC Fujian Petrochemical Complex (Sino-Saudi Gulei Ethylene Complex Project) in China's Fujian province.

SABIC FUJIAN Petrochemicals Co. Ltd, a 51:49 joint venture (JV) between SABIC Industrial Investment Co. and Fujian Fuhua Gulei Petrochemical Co. Ltd, decided to build the complex in Fujian's Gulei Industrial Park.

The complex will consist of a mixed feed steam cracker, with an expected ethylene capacity up to 1.8 million tpy. It will include a series

of world-class downstream facilities, including ethylene glycol (EG), polyethylene (PE), polypropylene (PP), polycarbonate (PC), and several other units.

Construction of the project is targeted for completion in 2026.

Abdulrahman Al-Fageeh, SABIC CEO, said: "The FID is a significant milestone for SABIC's business expansion and development in China. The project aims to support our goal of diversifying our feedstock sources and establishing a petrochemical manufacturing presence in Asia for a wide range of products."

### South Korea | LG Chem and Enilive move towards FID for biorefinery

LG Chem and Enilive have moved a step closer to final investment decision (FID) on a new biorefinery project in South Korea by signing a joint venture (JV) agreement.

In September 2023, Enilive (a company directly controlled by Eni, which holds 100% of its share capital) and LG Chem announced that they were exploring the possibility to develop and operate a new biorefinery at

LG Chem's integrated petrochemical complex in Daesan, with the aim to complete the biorefinery by 2026.

The aim is to process approximately 400 000 tpy of renewable bio-feedstocks using Eni's Ecofining™ technology and produce multiple products including sustainable aviation fuel (SAF), hydrotreated vegetable oil (HVO), and bio-naphtha. FID is expected in 2024.

### France | Michelin, IFPEN and Axens inaugurate plant producing bio-based butadiene

Michelin, IFPEN and Axens have inaugurated the first industrial-scale demonstrator of a plant producing bio-based butadiene in France, at Michelin's site in Bassens, near Bordeaux.

The demonstrator was built within the framework of the BioButterfly project, involving the three partners, and supported by the French Agency for Environment and Energy Management (ADEME) with the aim of developing and commercialising

butadiene from ethanol derived from biomass (plants), to replace butadiene from petrochemicals.

After launching in July 2023, the industrial-scale demonstrator must validate each stage in the manufacturing process of bio-based butadiene. In this way it is proving its technological and economic viability, with a production capacity of between 20 and 30 tpy – a scale which will enable rapid industrial development.



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# AUSTRALASIA:

**Nancy Yamaguchi, Contributing Editor**, discusses Australia's retreat from refining and the consequent impact on regional oil trade.

**A**ustralasia as a region includes Australia, New Zealand, Papua New Guinea (PNG), and a host of island nations spread across a vast swathe of ocean. Many of the island nations are sparsely populated and many miles distant from one another, yet there are many important diplomatic, cultural, and economic ties between them. Eleven countries are in the Commonwealth: Australia, Fiji, Kiribati, Nauru, New Zealand, PNG, Samoa, the Solomon Islands, Tonga, Tuvalu, and Vanuatu. Tokelau is a New Zealand Dependency, and Niue and the Cook Islands are sovereign states in free association with New Zealand. The Australian External Territories include Christmas Island, Norfolk Island, and the Cocos (Keeling) Islands. Nauru and PNG, now independent, were once part of the Australian External Territories.

These countries and dozens more cooperate in regional trade agreements including the Pacific Island Countries Trade

Agreement (PICTA), the South Pacific Regional Trade and Economic Cooperation Agreement (SPARTECA), and the Pacific Closer Economic Relations Plus Agreement (PACER Plus). Migration patterns create even stronger ties. For example, the census of 2021 counted the Cook Islands population at 14 987. However, approximately 80 000 people in New Zealand identified themselves as Cook Islanders or of Cook Islands descent, and approximately 28 000 in Australia did the same.

These myriad ties help explain the importance of what may appear to be minuscule volumes of petroleum fuel shipped from Australia and New Zealand across hundreds or even thousands of miles to small markets in the Pacific and Indian Oceans. A voyage from Geelong in Australia, the site of the Vitol Viva refinery, to Fiji is over 2200 nautical miles. A voyage from Geelong to the Cocos Islands is 3184 nautical miles. Yet LPG and other fuels were faithfully



# A TRIMMED-DOWN DOWNSTREAM

delivered to these and other far-flung islands for many years – until recently.

Australia, New Zealand, and to a lesser extent PNG, have been the focal points of Australasia's downstream petroleum industry. These countries were the only ones with a refining presence, and their ties to other island countries motivated them to develop and maintain trade links. This article discusses the wholesale retreat of Australasia's refining sector, the partial recovery in oil product demand, and the dramatic impacts on oil product trade.

## **Australasia's retreat from refining**

Australia is the key refining country in Australasia. It has a long history as a refining centre, but as time has passed, the facilities and technology-in-place have grown outmoded. The industry was characterised by medium-sized plants with gasoline-oriented upgrading. When Asia-Pacific oil demand

(dominated by diesel) surged, larger and more sophisticated refineries were built in countries including South Korea, Taiwan, Thailand, India, and China. Australian refineries began to lose their competitiveness. For a time, refineries remained viable by virtue of their access to domestic crude and feedstock supplies and their storage, transport, and retail infrastructure in local population centres. However, crude production from many of the older, established oilfields began to decline, and Australian refineries began to rely more on imported crude oil. Importing crude oil from the Middle East and then trying to export refined products into the Asia-Pacific market created exceedingly difficult economics.

According to the 'Australian Petroleum Statistics' data series published by Australia's Department of Climate Change, Energy, the Environment and Water<sup>1</sup>, Australian crude production has been declining at a rate of -2.4% per year



between FY 2010/11 and FY 2021/22. The Gippsland, Otway, and Bass Straits basins together have seen a decline averaging -10.9% per year during this period, and these producing areas were close to the now-closed Altona and Kurnell refineries. The focus of Australia's oil production shifted west, dominated by the Browse, Carnarvon, and Perth basins along the west and northwest coasts of the country. These are far from domestic refineries and population centres, especially with the closure of the Kwinana refinery. During the January - October 2023 period, only 22.2% of Australian refinery input was indigenous.

Australian crude refining capacity peaked at 829 000 bpd in 2002. It dropped below 700 000 bpd in 2006. Capacity collapsed to 443 000 bpd in 2015 before creeping back slightly to 455 000 bpd in 2019. Shell announced that it would convert its 85 000 bpd Clyde refinery to a product terminal in 2013. Shell sold its 118 000 bpd Geelong refinery to the oil trading company, Vitol, in 2014. Caltex closed its 135 000 bpd Kurnell refinery at the end of 2014. BP closed its 102 000 bpd Bulwer Island refinery in 2015.

The COVID-19 pandemic caused demand to collapse, forcing refinery margins into negative territory. Even sophisticated hydrocracking refineries in Singapore suffered negative margins in 2020 and 2021. According to the Energy Institute (EI) and BP in their Statistical Review of World Energy, margins were negative throughout 2020 and 2021, before recovering in early 2022 and then spiking at US\$20.66/bbl during 2Q22.

Table 1 summarises changes in Australasian refinery capacity. Crude capacity plateaued between 2015 and 2019, but the pandemic then brought down two of Australia's four remaining refineries plus New Zealand's sole refinery at Marsden Point. BP announced in October 2020 that it would close its Kwinana refinery in 2021 and convert it to a product import terminal. The Ampol Lytton refinery went early into extended maintenance in May 2020, stating that the pandemic had cut its refinery margin almost by half. The company did not commit to a full and permanent reopening. In 2022, ExxonMobil closed its Altona refinery. Viva Energy reduced throughput at its Geelong refinery by closing one crude tower

and the residual catalytic cracker, and the company announced that it was considering a full shutdown. The company shifted its refinery into maintenance ahead of schedule.

New Zealand's refinery had been Australasia's only hydrocracking facility. It was expanded and upgraded as part of the government's 'Think Big' energy projects after the oil price shocks of the 1970s. When the petroleum industry was deregulated in 1984, the refinery was transferred to the New Zealand Refining Company, a consortium of the five major retailers, later led by BP, Mobil, and Z Energy. Government and industry worked for years to keep the refinery afloat. However, in 2021, the shareholders voted to stop refining. The Marsden Point location became a product import terminal, and the company was renamed Channel Infrastructure.

Although two refineries remain in Australia, they too considered closure, and they remained in operation in part because of government-industry negotiations. The government decided that a 'sovereign fuel supply' was essential to Australia's energy security, and it launched a programme of production payments to assist the two remaining refiners.

Figure 1 illustrates the dramatic reduction in Australian refinery production between 2011 and the first 10 months of 2023. In 2011, refinery output averaged 710 000 bpd. Production fell below 500 000 bpd in 2015, and it stabilised in this vicinity until the COVID-19 pandemic forced more refinery closures. Output fell to 251 000 bpd in the January - October period of 2023, and it is possible that, without government intervention, Australian refinery output would have been zero.

Figure 2 presents the phase down and ultimate disappearance of New Zealand's refinery output, as published by the New Zealand Ministry of Business, Innovation and Employment.<sup>3</sup> Refinery production had been stable in the range of 100 000 - 110 000 bpd in the decade leading up to the pandemic, upon which refinery output was cut to 81 000 bpd in 2020 and 2021. Still, prospects for the refinery's profitability were deemed poor. The decision was made to close the refinery after 1Q22, and output averaged 20 000 bpd that year. In 2023, output was zero.

PNG became the third Australasian country with a refining presence when InterOil Corp. completed its Napa Napa refinery at Port Moresby in 2004. The refinery had a crude refining capacity of 32 500 bpd, a 5000 bpd hydrodesulfurisation (HDS) unit, and a 3500 bpd catalytic reforming unit. PNG's high-quality sweet crude enabled production of fuel of adequate quality for the domestic market, while allowing some exports, chiefly naphtha.

The US Energy Information Administration (EIA) reported that PNG refinery output fluctuated between 17 000 - 27 000 bpd between 2005 and 2014, implying typical utilisation rates of 50 - 80%. In 2014, Singapore-based Puma Energy Holdings Pte purchased InterOil's refinery, fuel terminals and service stations. The company does not publish refinery data, merely reporting a total volume of 'Asia-Pacific throughput volumes' in its

**Table 1. Changes in Australasian refinery capacity ('000 bpd)**

Closures	Capacity ('000 bpd)	Year closed
Australia, Clyde	85	2013
Australia, Kurnell	135	2014
Australia, Bulwer Island	102	2015
Australia, Kwinana	137	2021
Australia, Altona	80	2022
New Zealand, Refining NZ	135	2022
Total	674	
<b>Remaining</b>		
Australia, Lytton	109	
Australia, Geelong	118	
PNG, Port Moresby	33	
Total	260	

Source: author's compilation



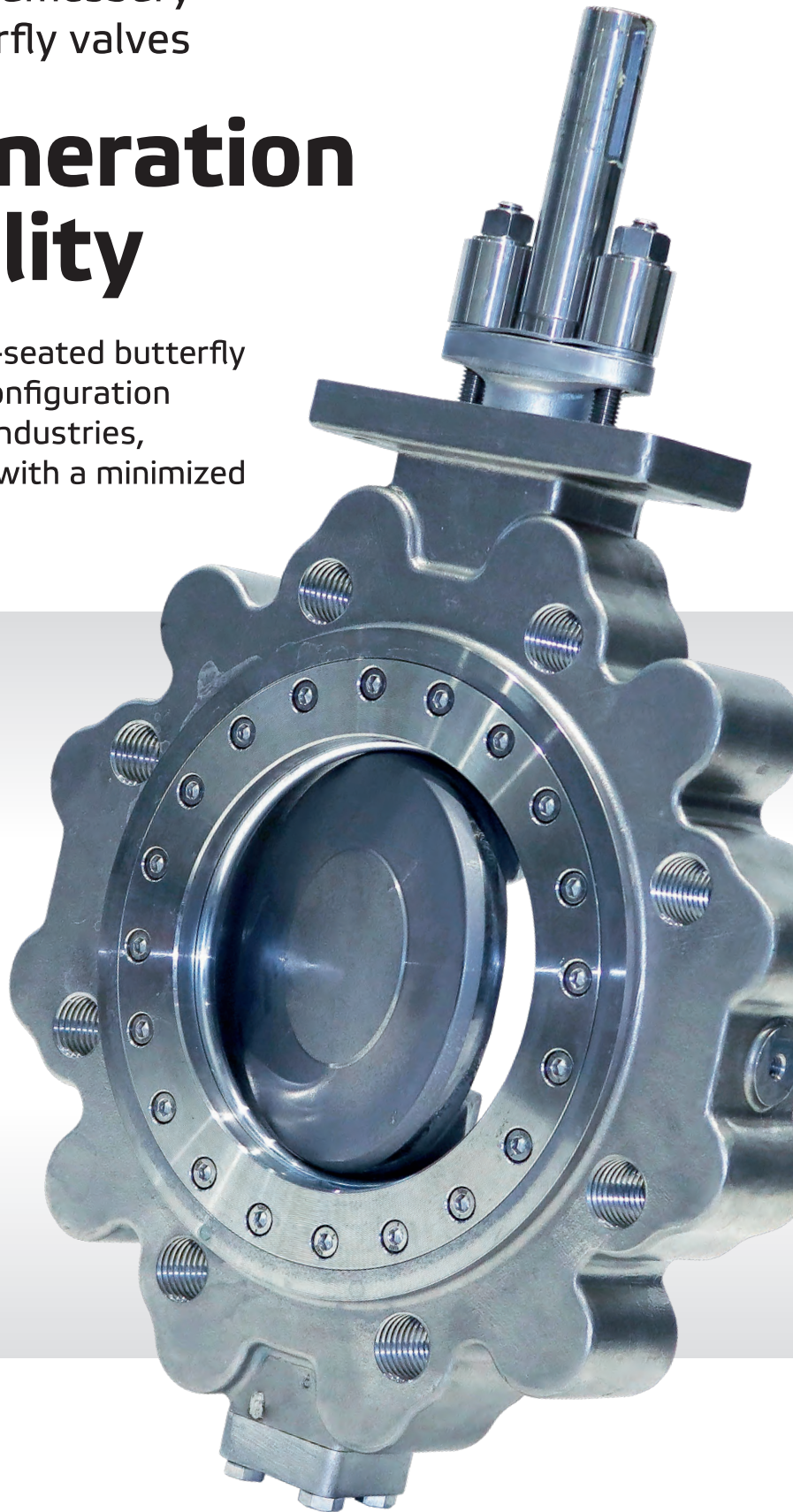
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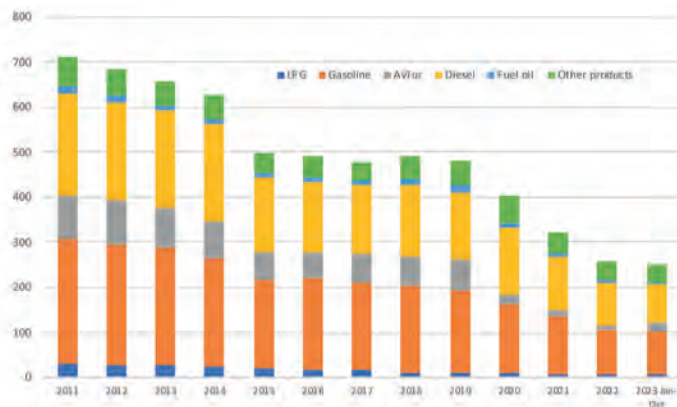
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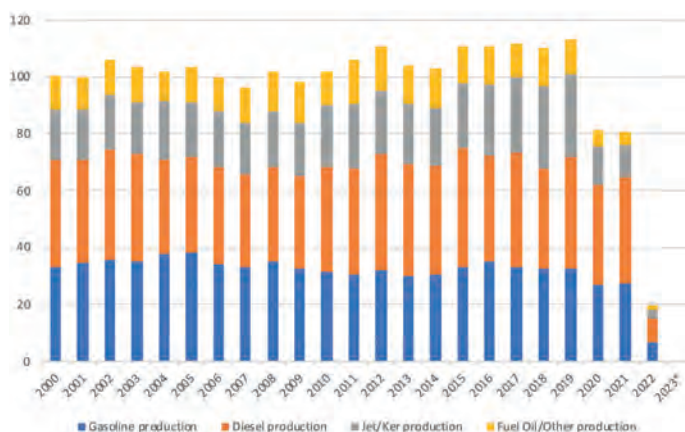
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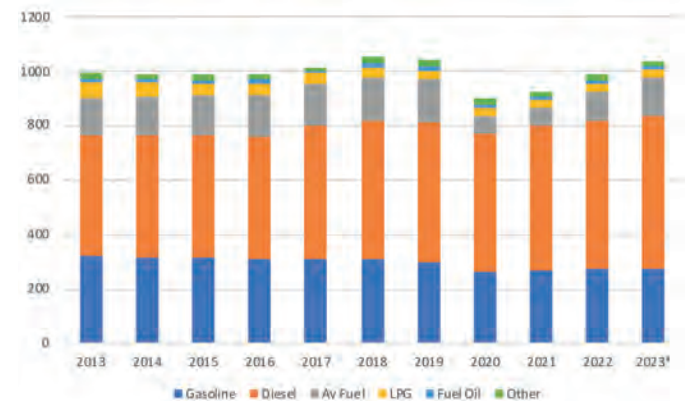
quarterly reports. If this is taken as refinery throughput, it has been very low recently: approximately 6500 bpd in 2021, 6600 bpd in 2022, and 5400 bpd during the first three quarters of 2023 – equating to utilisation rates of 17 - 20%. The EIA data for the decade leading up to Puma Energy’s purchase of the refinery indicates that the refinery produced an output of



**Figure 1.** Dramatic downturn in Australian refinery production ('000 bpd).



**Figure 2.** New Zealand refinery output vanishes ('000 bpd). Source: New Zealand Ministry of Business, Innovation & Employment. \*2023 data is complete through 3Q23.



**Figure 3.** Australia refined product sales ('000 bpd). Source: Australian Petroleum Statistics. \*2023 data is complete through October.

roughly 41% diesel, 10% kerosene and jet fuel, 4% gasoline, 13% fuel oil, and 30% other products, mainly naphtha when the input feed is light sweet crude.

## Australasian oil demand in slow recovery

The previous paragraphs recount a dramatic fall in Australasian refined product supply. The pandemic also cut demand sharply, but has demand recovered to pre-pandemic levels?

### Australian oil product demand

Australia’s refined product market had been on a predictable course before the pandemic hit: growth in diesel and aviation fuel demand, decline in gasoline and LPG demand, and flattish demand for fuel oil and other products. Over the past decade, total refined product demand grew at a rate averaging 0.8% per year from 2013 to 2019. Total demand in 2019 was approximately 1 042 000 bpd. The pandemic caused a sharp drop of 143 180 bpd (14%) of demand in 2020. The drop consisted mainly of jet fuel and gasoline, as the country launched stay-at-home orders and tourism fell. Demand is now in recovery. From 2021 through the first ten months of 2023, demand has recuperated at an average rate of approximately 5% per year. During the first ten months of 2023, demand averaged 1 037 200 bpd, nearly back to its pre-pandemic level. This trend is shown in Figure 3.

### New Zealand oil product demand

Figure 4 presents the trend in New Zealand’s oil product demand during the decade 2013 - 2023, with 2023 estimated using data for the first three quarters. Demand grew at a rate of 0.5% per year on average during the past decade. Gasoline and fuel oil demand declined, while demand rose for diesel and aviation fuel. The COVID-19 pandemic caused demand to drop by 29 000 bpd (18%) from 2019 to 2020. Since then, demand recovery has been slow, and demand has not returned to its pre-pandemic level. In 2019 demand was approximately 162 000 bpd, recovering to only 144 000 bpd during the first three quarters of 2023.

## Shifts in Australasian product trade

The drop in refinery production, coupled with a gradual recovery of demand, is causing a heavier reliance on imported fuels. Figure 5 shows the growth in Australia’s product imports. In 2011, product imports totalled 343 000 bpd. Imports expanded to 636 000 bpd in 2019, until the pandemic caused a dip to 587 000 bpd in 2020. In 2020 - 2023, however, refinery output fell, and demand began to recover. Imports surged to 896 000 bpd during the first ten months of 2023.

During the period from 2011 to 2023, imports have grown at an average rate of 8.3% per year. The fastest rates of growth were for the high-value products: jet fuel (10% per year) diesel (9.6% per year), and gasoline (9.8% per year). Imports of fuel oil and LPG have declined. Australia’s diesel balance is drastically lopsided toward imports. Australian refineries produced only 82 600 bpd of





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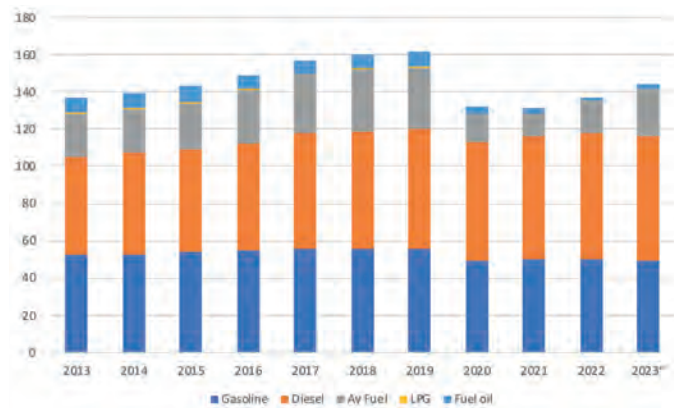
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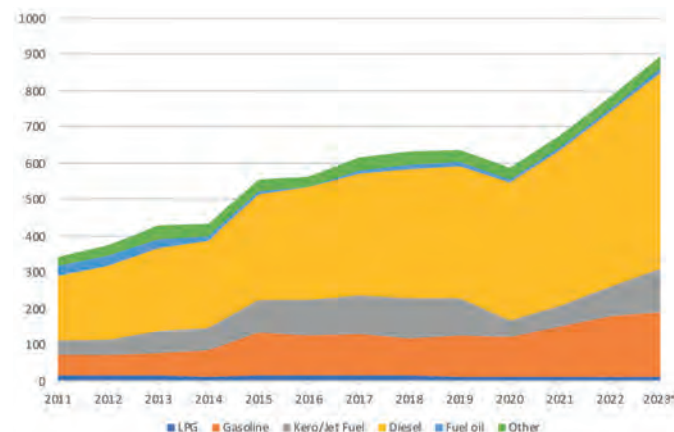


diesel in January - October 2023, whereas demand was 548 000 bpd, making Australia dependent on imports for around 85% of domestic diesel demand.

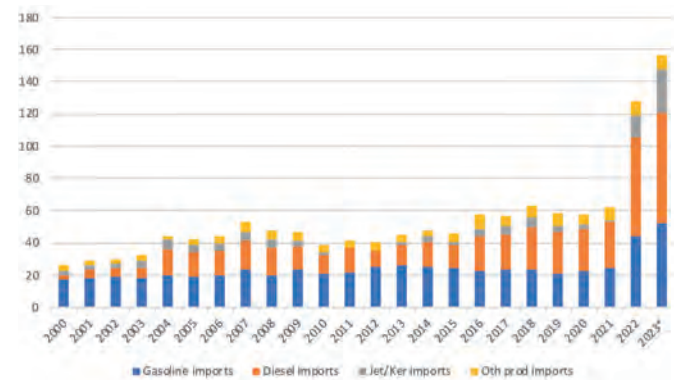
Australia is a significant product trader, but its product exports are dominated by LPG. In 2011, product exports were



**Figure 4.** New Zealand oil product demand ('000 bpd). Source: New Zealand Ministry of Business, Innovation & Employment. \*2023 data is complete through 3Q23.



**Figure 5.** Dramatic growth in Australia's product imports ('000 bpd). \*2023 data is complete through October.



**Figure 6.** New Zealand product imports jump after refinery closure ('000 bpd). Source: New Zealand Ministry of Business, Innovation & Employment. \*2023 data is complete through 3Q23.

51 900 bpd, 37 200 bpd (72%) of which were LPG. Exports of non-LPG products ranged from approximately 10 000 bpd to 25 000 bpd. Because Australia is so large and has so many ties to neighbouring Australasian countries, many small trades remain to balance supply and demand, to export specialty products, and to provide fuel to countries including the Solomon Islands, Vanuatu, Christmas Island, Fiji, and other neighbours. One trade pattern has essentially vanished, however: Australian exports of crude oil and refinery feedstocks to New Zealand and PNG. In 2012, for example, PNG imported 828.2 ML of crude and refinery feed from Australia. This fell to 1.8 ML in 2022. New Zealand imported 354 ML of crude and feedstocks from Australia in 2012, and this fell to 10.2 ML in 2022. As Figure 6 illustrates, the closure of New Zealand's sole refinery in 2022 caused a jump in product imports. Imports had been in the vicinity of 50 000 - 60 000 bpd prior to the closure, upon which they jumped to 128 000 bpd in 2022 and 156 000 bpd in Q1-3 of 2023.

Before its refinery closed, New Zealand had been a modest exporter of refined product, typically 2000 - 6000 bpd to neighbouring Australasian countries. These exports vanished in 2023.

## A downsized downstream

Australasia's downstream petroleum industry has never been considered a titan on the global scene, yet it played a significant role in the region. It captured some value-added from processing locally produced refinery feedstocks, it provided employment and bolstered local economies, it supplied fuel to domestic markets, and it shipped product to small island countries in the Pacific and Indian oceans. Although the volumes were small, they reinforced economic and cultural ties among Australasian countries.

Refinery profitability was often threatened. The downstream industry appeared to be in orderly retreat, until the COVID-19 pandemic made remaining refiners stampede for the exits. Australia has only two refineries left, and they too had made exit plans that were forestalled only through government intervention.


It is sometimes easy to dismiss the importance of Australasia's downstream industry. After all, the five recently shut refineries in Australia had a capacity of only 539 000 bpd all told, which is less than many single refineries in Asia, including ExxonMobil's Jurong refinery in Singapore (605 000 bpd), GS Caltex's Yeosu refinery in South Korea (730 000 bpd), and Reliance Industries' Jamnagar refinery in India (1 240 000 bpd). Large, sophisticated refineries in densely populated areas have enormous economic advantages. An entrepôt refining centre like Singapore is capable of blending and delivering on-spec product anywhere in the world. A stereotypical Texan oilman might regard the amount of fuel delivered to a small island country as laughable – he could say that more fuel is used to find a parking space at the Houston Galleria. Yet many island nations have looked to Australia and New Zealand for fuel supply for decades, and now they must look elsewhere – as indeed do Australia and New Zealand. Australasia's downstream



industry remains important to Australasia. Its drastic downsizing now puts Australasia in the market for over 1 million bpd of refined product from neighbouring regions. As time passes, will Australasian consumers face higher prices and regret the loss of their own industry? Or will a regime of higher prices quench demand growth?

For the time being, Australasia's growing import needs have been met with relative ease, given extensive refinery capabilities in the rest of the world, and the slow recovery of demand following the COVID-19 pandemic. As noted, however, refinery margins spiked in 2Q22, greatly enhancing refiner profits for those who had survived the downturn. It is possible that supply chain disruptions could tighten supply, particularly as demand grows and geopolitical risks continue.

This might bode well for the future profitability of the three remaining Australasian refiners, but it could mean higher fuel prices for consumers. In Australia, for example, automotive diesel prices had sagged to AU\$117/litre during 4Q20 during the pandemic, but as demand picked up, regional refineries struggled to ramp up, and inflation rose, diesel prices jumped to AU\$222/litre in 4Q22 – a price increase of nearly 90%. The true delivered cost of fuel to distant islands could be enormous, and many governments actively administer prices to shield consumers from price spikes – though naturally the cost of government subsidies eventually filters down to the consumer.

The topic of global warming offers a final note on Australasia's oil sector. The Pacific Islands are considered the front line in the battle against climate change. The population relies heavily on threatened ocean and coastal resources. Many atolls and islands are only a few feet above sea level. Many have coral reefs that are essential to the ecosystem, and they may serve as ecotourism destinations. Australia and New Zealand have committed themselves to reducing carbon emissions, but several island nations have been critical of their progress, particularly Australia's. According to the EI/BP Statistical Review, Australia cut its carbon dioxide equivalent emissions at an average rate of only -0.2% per year during the 2012 - 2022 decade. In contrast, New Zealand cut its carbon emissions at a rapid rate of -1.7% per year during the decade, surpassing the EU's achievement of -1.6% per year. A key reason is Australia's devotion to its coal industry. Australia relied on coal for 26% of its primary energy needs in 2022, and it is the largest coal exporter in the world. Cutting coal use would have the largest impact on cutting carbon emissions, but all fossil energy use is under pressure, which might place a lid on future refining and oil consumption. Australia may commit itself more vigorously to the battle against climate change to remain a good neighbour and a leader in the vast Australasia region. 

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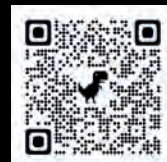
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5. [www.pumaenergy.com](http://www.pumaenergy.com)

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# DEFENDING AGAINST VAPOUR DRIVE







**Cassandra Popovski, Owens Corning**, explains why keeping vapour driven moisture out of insulation systems should be a high priority in hydrocarbon processing environments.

If you have ever picked up an iced drink from a table and noticed a ring of water left behind, you have seen the effects of vapour drive. While such an everyday example is relatively harmless, in hydrocarbon processing environments such as LNG facilities or petrochemical applications, vapour drive can lead to a range of costly and potentially dangerous consequences.

This article will examine potential risks that vapour-driven moisture poses to insulation systems in hydrocarbon processing facilities. It will start by looking at the relationship between humidity, dew point, and vapour pressure.

### **Humidity, dew point, and vapour pressure**

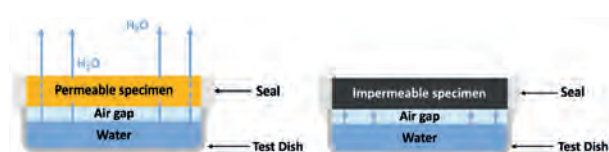
Air is not just a mixture of nitrogen and oxygen. It also contains other gases, such as carbon dioxide (CO<sub>2</sub>),

hydrogen and water vapour, as well as contaminants. There are a number of ways to express the concentration of water vapour in the air. One example is absolute humidity, which is a measure of the moisture content of air at a given temperature. Another example is relative humidity, expressed as a percentage, which compares the actual amount of moisture in air to the amount that it could potentially hold at that temperature. Air at higher temperatures can hold more water vapour than at lower temperatures, so when air temperature cools (assuming constant pressure), water vapour condenses as liquid water or dew. This temperature is referred to as the dew point.

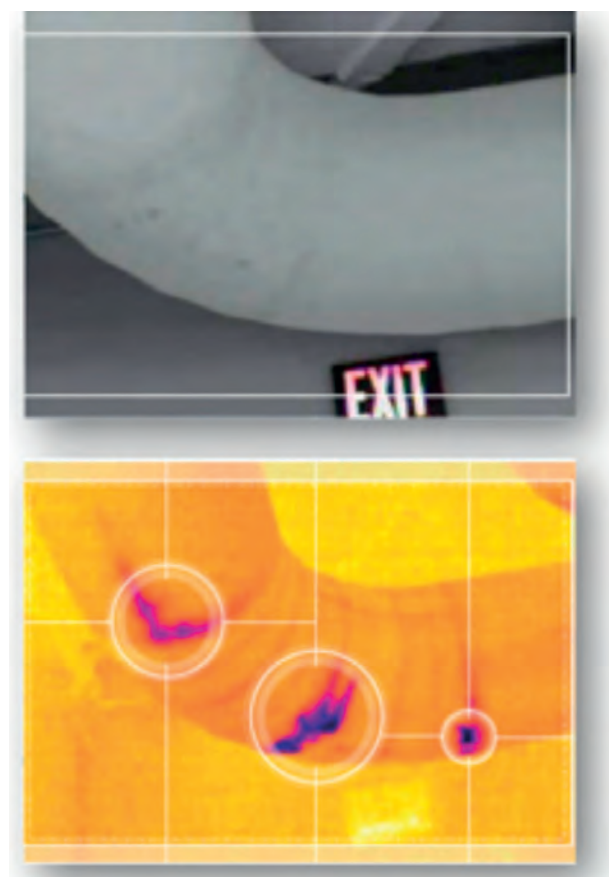
Vapour pressure is the pressure exerted by a vapour that is in equilibrium with its condensed phase at a given temperature. Vapour pressure increases with temperature, and in warmer air, spaces of higher vapour pressure will

move vapour toward colder areas of lower vapour pressure. This tendency of vapour in the air to move from warm to cold areas is commonly referred to as ‘vapour drive.’ When below-ambient pipes are surrounded by warm air, vapour drive will move the warm air towards the cool air local to the pipe, at which point water in the air is likely to condense. If the cold pipes are insulated, condensation can even form on the outside of the insulation system. This is the same concept as the iced drink example.

Why is moisture such a big concern when it comes to insulating pipes? It has been estimated that 98% of the problems with insulation systems are due to moisture.<sup>1</sup> This shows just how important designing an insulation system to keep moisture out can be.



**Figure 1.** Cellular glass insulation is a closed-cell material that has demonstrated impermeability during standards-based testing and in application.



**Figure 2.** Thermal assessment of jacketed piping can be a way to detect problems before physical symptoms manifest.

## Vapour drive, cold pipes and permeability problems

Insulating cold process pipes, such as those used in LNG processes, presents additional challenges compared to pipes running closer to ambient temperatures. Many processes used in hydrocarbon facilities run at temperatures significantly below ambient conditions. For example, piping for LNG operates at about  $-162^{\circ}\text{C}$  ( $-260^{\circ}\text{F}$ ). The temperature difference between cold pipes and hot, humid air can result in vapour drive, forcing moisture through the insulation onto the pipe. Vapour drive may also cause moisture in the ambient air to settle as condensation on the insulation exterior.

The ever-present threat that vapour drive poses to cold process pipes – particularly those in warmer climates – can lead to problems when a permeable insulating material is used.

When permeable insulation is exposed to vapour drive, moisture can penetrate the insulating system where it can present as any of the threats discussed below.

### Threat 1: insulation and pipe damage

When liquid or vapour moisture breaks the insulating system barrier, corrosion can form under insulation and degrade pipes. This is primarily a concern for pipes that operate between  $-4^{\circ}\text{C}$  and  $175^{\circ}\text{C}$  ( $25^{\circ}\text{F}$  and  $350^{\circ}\text{F}$ ), but it can also affect pipes and equipment that experience temperature cycles or frequent system shutdowns.<sup>2</sup> Degradation may continue undetected for many years, diminishing the efficiency of the insulating system and process pipes. Corrosive issues can lead to early failure of the piping system. Unexpected downtime may result if the facility has to halt processes in order to repair or replace insulation and damaged piping or equipment.

### Threat 2: safety issues

Workplace hazards can stem from issues posed by vapour drive. When pipes carry materials at below-ambient conditions, there is a risk that moisture builds up on the outside of the insulation and freezes. If the insulation is permeable, it can absorb water to create a mass of ice. This creates a safety hazard for employees as piping may be placed in higher areas where ice chunks can fall from the insulation, striking those below.

Left unchecked, corrosion under insulation can breach the piping system, allowing pipe contents to leak, exposing employees to potentially harmful materials and creating risks for environmental safety. Petrochemical and hydrocarbon leaks can pose an environmental risk on site and for surrounding areas.

Fire risk is another safety concern. When hydrocarbon materials leak, volatile and combustible materials create safety risks and conditions with the potential for fire or explosions that can threaten both employees and nearby facilities.

### Threat 3: reduced operating efficiency

It has been proven that when moisture penetrates a permeable insulating material, the thermal conductivity of the insulation is higher, therefore decreasing the



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insulation's performance.<sup>3</sup> This drop in performance adds additional strain to the entire process as more energy is needed to maintain temperatures, and cooling systems must work harder to chill pipe contents. As more energy is consumed, costs to run the facility may rise and energy efficiency may be negatively impacted. Other problems can also occur. For example, loss of process control can lead to an increased need for repairs – and repair costs – to fix or replace parts of the affected system. When insulation does not function adequately, another potential result could be that cryogenic liquids start reverting to a gaseous state.

It is important to keep in mind that while not a threat itself, the practice of 'value engineering' can present unintended consequences. When specifying materials for insulating systems on process pipes, specifiers should consider future costs if a less expensive, permeable insulating material becomes damaged. While an impermeable insulation, like cellular glass insulation, may have a higher upfront material cost, its use can result in a lower cost over time as it helps protect the long-term integrity of piping and processes (see sidebar).

## Impermeability – the key to defending against vapour drive

For the reasons described above, keeping vapour-driven moisture out of the insulation system should be a high priority. While protective elements like mastics, vapour barriers and jacketing can be added, they should not be the only line of defence against the risks posed by vapour drive. Specifying an impermeable insulation, like cellular glass, can help protect pipes from moisture entering the insulation system through vapour drive. Impermeability means that a material will not allow liquids or gases to pass through. The key to an insulation's performance is its composition. Cellular glass is comprised of sealed glass cells that prevent moisture from breaching the insulation system. In addition to being impermeable, cellular glass is also non-combustible and offers high compressive strength.

Cellular glass insulation is complemented by a system of components that properly seal joints and protrusions. This system approach ensures that joints and protrusions are sealed and do not provide any point of ingress or path for moisture to enter under the insulation.

## Impermeable and closed cell are not the same

While some types of closed-cell insulating materials are impermeable to moisture, not all closed-cell insulations have the same impermeability. This is an especially important point to consider when working in extremely cold temperatures like those used in LNG processes. For example, both cellular glass insulation and polymeric insulation can be considered closed-cell materials, but cellular glass insulation is the only truly impermeable insulation material.

Insulation materials should be tested for permeability by the ASTM E96 Standard Test Methods for Water Vapour Transmission of Materials. This standard considers two methods: procedure A (desiccant 'dry cup' method) and procedure B (water 'wet cup' method). Procedure B is generally considered the more aggressive method and the

## Defending against vapour drive in a tropical location

Petrochemical and hydrocarbon processing facilities working with materials well below ambient temperatures face additional risk from moisture when they are located in hot, humid climates. A petrochemical facility located in a tropical region demonstrated the importance of selecting the right insulation in a challenging environment.

The facility originally insulated cold tanks and process piping using an open-cell, permeable insulating material. When moisture penetrates permeable insulation, corrosion can form and the insulation itself can be damaged by the build-up of water and ice. At the South American facility, moisture found a way into the insulation and the entire system failed about 10 years after it was installed.

All the permeable insulation installed on multiple storage spheres had to be replaced and the tanks had to be checked for corrosion and other damage. After the facility evaluated strategies for replacing the insulating system, it selected impermeable, cellular glass. The benefit of this decision was verified 10 years after its installation when the insulating system was evaluated using thermal imaging. In addition, inspectors found no corrosion under the insulation and little to no loss of thermal performance. The use of cellular glass insulation demonstrated that it is possible to design insulation systems for long-term use in challenging environments when impermeable insulating materials are specified and properly installed.

more representative of the two methods for determining the permeability of insulation material in application.

The testing procedures look at the movement of water vapour through a material when the material is exposed to a situation where one side experiences high humidity conditions and the other side of the material is in a low humidity situation. In dry cup testing, ambient moisture from the testing chamber must move through the insulating material to reach a desiccant held within a test dish. In wet cup testing, humidity from a test dish must travel through the test specimen into the testing chamber.<sup>4</sup> Cellular glass insulation has been tested using ASTM E96 Procedure B and is rated as having a water-vapour permeability of 0.00 ng/Pa·s·m (0.00 perm-inch).

The emissivity of jacketing used with an insulation system should also be considered. Emissivity refers to the ability of a material's surface to emit energy as thermal radiation. Reflective materials, like metal jacketing, that emit little radiant energy have lower emissivity, while a nonreflective material will have a higher emissivity. For below ambient piping, jacketing materials with lower emissivity values will have a cooler surface temperature compared to jacketing materials with higher emissivity values. Because of the cooler surface temperature, condensation can occur more easily with the lower emissivity jacketings compared to the higher emissivity jacketings. By using a material with slightly higher emissivity (e.g. 0.9 instead of 0.4), although the system gets marginally warmer, it protects against a higher relative humidity level. The effect of heat gain due to the emissivity value differences can be considered minimal in most cases.



## Installation, maintenance and inspection


Correct installation is key to an effective insulating system. Owens Corning's technical service team provides onsite training to ensure workers on the jobsite know how to handle and properly install materials.

Once insulated piping is installed, it should regularly be inspected for signs of damage. Insulation can be damaged by various processes in the facility, including nearby maintenance or weight from workers standing or walking on equipment.

Visual indications of damage to pipe insulation and moisture within the insulation can include excessive condensation collection, visible pooling or leaking, frost on the outside of the insulation, frozen insulation and bulging or damaged insulation. Before visible symptoms – like ice formation – appear, there can be more subtle signs and potential warnings that insulation is no longer functioning correctly. These include increased energy use, which suggests a loss of system efficiency and reduced thermal performance.

Following installation, regular inspection by a certified mechanical insulation inspector is recommended. Several organisations have this type of certification, including the National Insulation Association (NIA) and the Committee Industrial Insulation (CINI). Insulation should be checked for performance and tight joints, thorough and water-tight sealings, and a uniform finish that is free of defects.

In summary, moisture that infiltrates permeable insulation on cold piping can cause problems ranging from reduced process efficiency to increased maintenance costs. Other significant issues include the risk of corrosion under insulation (CUI) formation and elevated safety risks for employees and the environment.

These risks can be mitigated by designing an insulation system that includes an impermeable insulation such as Owens Corning® FOAMGLAS® cellular glass insulation. The material operates in a wide temperature range and maintains its impermeability at low temperatures. It also does not wick or absorb moisture, including hydrocarbons, meaning it will not collect fuel or burn in the event of a leak. Threats posed by vapour drive can be mitigated for cold and cryogenic piping if the insulation system uses an impermeable insulation to defend against moisture. 

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# Understanding corrosion in amine and sour water systems





**Ralph H. Weiland, Optimized Gas Treating Inc. (OGT),** reveals how acid gas corrosion can be understood from the perspective of chemistry.

**T**he focus of this article is on understanding acid gas corrosion in alkaline amine and sour water systems from the perspective of basic chemistry. Some underlying tenets are presented and developed to explain observations and common symptoms seen in operating plants. The discussion is simplified as follows:

- Carbon steel: stainless steels (austenitic in particular) are much more resistant to this type of corrosion, and it is recognised that they can be used, albeit at a higher investment cost. The primary issue however, is to understand when carbon steel may be a poor metallurgical choice.

- Alkaline environments: many of the concepts apply equally to pH-neutral and acidic systems. However, the level of corrosion data for modelling is much sparser and these areas exist primarily in the regenerator overhead acid gas circuit. Acidic systems are outside of the scope of this article.

### **Tenet 1: the amine (or $\text{NH}_3$ ) is not corrosive**

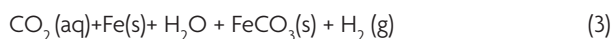
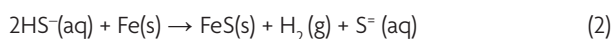
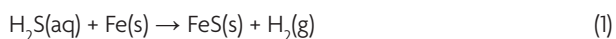
Despite being completely incorrect, the industry continues throwing around such terms as 'amine corrosion' and 'alkaline stress corrosion cracking' to describe corrosion that, at the root level, is really caused by dissolved acid gases, not the amine.



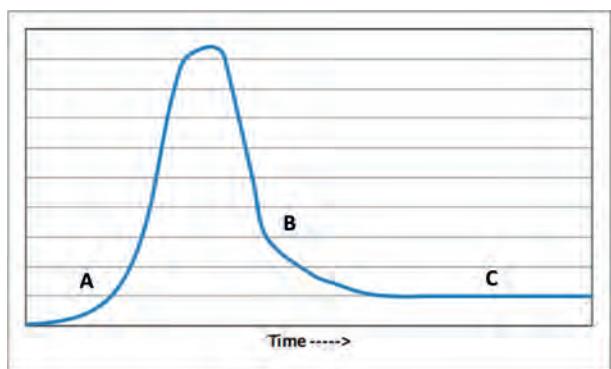
As early as 1955, Polderman et al reported that 20%wt monoethanolamine (MEA) solution without acid gas was less corrosive to steel than pure water.<sup>1</sup>

It is true that some amine systems appear to be more susceptible to corrosion than others. The reason for this is that the activity of the dissolved acid gas species changes with the amine type, its concentration, the acid gas loading, and the temperature. The amine type itself, however, is not directly responsible. The dissolved acid gas species of interest are: bisulfide ion ( $\text{HS}^-$ ), free physically dissolved hydrogen sulfide ( $\text{H}_2\text{S}$ ), bicarbonate ion ( $\text{HCO}_3^-$ ) and free physically dissolved carbon dioxide ( $\text{CO}_2$ ). Carbonate ( $\text{CO}_3^{2-}$ ) and sulfide ( $\text{S}^{2-}$ ) are themselves oxidation products that cannot donate the proton necessary for reaction with the iron in carbon steel and, therefore, are inherently noncorrosive. The corrosivity of  $\text{CO}_2$ ,  $\text{H}_2\text{S}$ , bicarbonate and bisulfide depend on the activity of these species, not their concentration.

In their simplest stoichiometric form, the basic corrosion reactions of dissolved  $\text{H}_2\text{S}$  and  $\text{CO}_2$  species with iron are as follows:



The oxidation reaction with  $\text{H}_2\text{S}$  is faster than with bisulfide; however, the alkalinity of the amine (and ammonia) solutions means that the dissolved  $\text{H}_2\text{S}$  is predominantly in the bisulfide form, with very little remaining as free molecular  $\text{H}_2\text{S}$ . This is also true of dissolved  $\text{CO}_2$ . The concentrations of free acid gases are pH dependent, and pH is a function of amine strength, total dissolved acid gas, temperature and, to a lesser extent, heat stable salt (HSS) concentrations. However, HSSs and their concentrations do affect the speciation of the solution, especially in lean solvents. As discussed later, certain HSSs, notably bicine, can chelate iron and thereby significantly accelerate corrosion.



**Figure 1.** Corrosion vs time for steel passivation.

When  $\text{H}_2\text{S}$  reacts with the iron in carbon steel, solid iron sulfide precipitate is formed, along with hydrogen gas. Since both reactions transcend phase boundaries and create reaction products in completely different phases (for example, hydrogen is generated into a separate phase), it follows from Le Chatelier's principle that there is a powerful thermodynamic driving force causing corrosion to occur. What limits the reaction is primarily the presence and the amount of bare unreacted iron at the steel surface. A secondary factor is the concentration of dissolved acid gas reactant, i.e.,  $\text{H}_2\text{S}$ . The dissolved  $\text{H}_2\text{S}$  concentration can be regarded as another parameter. In an attempt to control the concentration of dissolved acid gas, many practitioners have adopted upper limits on the acid gas loading of the rich amine.

## Tenet 2: iron sulfides can protect against further corrosion

If in a new amine unit (one that had never previously been exposed to  $\text{H}_2\text{S}$ ) one were to plot corrosion rate as a function of time, the plot qualitatively would look similar to the one shown in Figure 1. This is for the period immediately following  $\text{H}_2\text{S}$  introduction. There is an initial period (Region A) during which the corrosion rate climbs almost exponentially as the fresh iron is exposed to dissolved acid gas. This is followed by a period during which the corrosion rate levels off and then falls (Region B) as the iron sulfide film begins to block or occlude contact of fresh  $\text{H}_2\text{S}$  with the iron. Eventually, once the iron sulfide layer is established, the system settles down to the nominal and, hopefully, low residual corrosion rate shown in Region C.

If one were to examine the steel surface with an electron microscope, the iron sulfide protective layer would appear to be imperfect. This is primarily the result of evolution of hydrogen gas that is formed as a product of the corrosion reaction itself. Because of this, a residual nominal corrosion rate is expected and observed in operation. It is the quality of the iron sulfide protective layer or film that dictates the final, residual corrosion level for the system.

The corrosion rates in Region A are commonly observed during initial startup or following a turnaround after a chemical cleaning (especially acidising types) has been conducted. The amine will typically appear black from the macroscopic iron sulfide particles that are suspended in solution and absorbing light. A period of hours to weeks can pass, during which particle filters will plug and require change-out almost immediately after being placed in service. Measurements by Cummings et al on a bench-scale mini-amine plant with relatively lean amine, indicated in some cases over 600 mils per year (mpy) corrosion rate during this phase of operation.<sup>2</sup>

As the steel begins to passivate (Region B), solid iron sulfide particles will grow and begin to find homes either in a filter element (desired), or by settling out on trays or equipment and piping low points (undesired). As the solution clears of iron sulfide particles, the colour will change from black to dark green, and then paler green (microscopic iron sulfide particles). Ultimately the solvent



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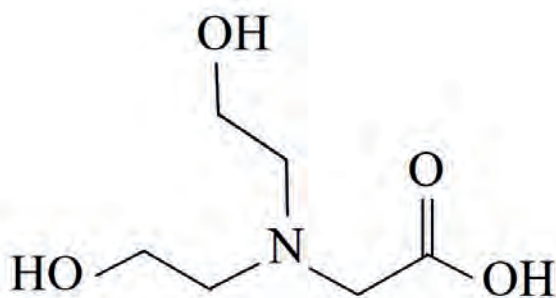
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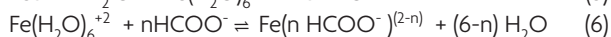
**Figure 2.** Structure of bicine.

should return to clear and either colourless, or with a slight amber colouration.

Managing corrosion begins with preservation of the protective iron sulfide film. Velocity creates shear stress on the pipe surface and the shear force can be sufficient to rip off the imperfect iron sulfide layer. This exposes fresh steel, and corrosion locally increases in the area of this high velocity and high shear rate. The iron sulfide particles that are dislodged can subsequently act as a scouring agent to increase corrosion in other areas of the plant. Furthermore, wherever velocity is reduced, the particles can settle out in unwanted places.

For these reasons, the gas treating industry has generally adopted velocity limits for carbon steel piping in amine service. Lean amine velocities are typically held to 7 - 10 ft/s while rich amine velocities are commonly held to 3 - 5 ft/s. Special care should be taken in areas of the plant where two-phase flow (flashing) can occur as this can result in extraordinarily high velocities, slug flow, and very high corrosion rates, certainly reaching more than 10 mpy. Rich amine level control valves, pressure letdown valves and the heated rich amine outlet from the lean-rich exchanger are special problem areas and are often constructed using austenitic stainless steel (304L or 316L SS).

Just as shear stress can physically accelerate corrosion, reactions can accelerate corrosion by chemical means. Through chelation, insoluble iron sulfide can be converted into an ionic complex that is dissolved in solution. The equilibration between the iron sulfide present on the steel surface (FeS) and the complexed iron can be expressed as a solubility product through the following chemistry<sup>2</sup> exemplifying iron chelation by formate ion (HCOO<sup>-</sup>):



Metallic iron is insoluble in water, even at high temperatures. However, reaction (6) provides a sink for iron. Complexed iron is in a different phase than the iron sulfide reactant, so the driving force can be significant. This chemistry leads to an impressive transport mechanism for accelerating corrosion that works as follows:

- Equation (5) shows that the presence of H<sub>2</sub>S loading as bisulfide ion (HS<sup>-</sup>) drives the system towards the left. Therefore, H<sub>2</sub>S loading tends to promote a stable iron sulfide protective film.

- HSSs are stripping promoters and reduce the lean loading, tipping the equilibrium of (5) towards the right.
- Additionally, the complex provided by the HSS anion – formate ion in Equation (6) – further pushes the reactions towards destabilisation of the iron sulfide film.
- The complexed iron is not filterable and travels in a form that appears to the naked eye as yellow-tinted amine to an absorber where the H<sub>2</sub>S concentration is higher.
- At the higher H<sub>2</sub>S concentrations in a typical absorber, the equilibrium is shifted away from complexation and back to making iron sulfide corrosion product. This time, however, instead of being on the pipe surface, the iron sulfide is present as variously sized particles inside the contactor. It leaves with the rich amine and travels to other points in the treating plant.

## Bicine

Bicine (Figure 2) has received considerable attention as a pernicious bane for corrosion in amine systems.<sup>3,4</sup> As an amino acid, bicine is a zwitterion, but although it is an ion, it is close to being a neutrally charged molecule under the pH conditions extant in amine systems. Typical of all amino acids, bicine has both an amino functional group and an acidic (HSS) group. By all indications, the zwitterionic or hermaphroditic nature of this molecule appears to give it the characteristics of a very strong iron chelator. In many cases, the concentrations at which serious corrosion has been reported seem to be higher (several weight percent in solution) than those typically encountered with HSSs. There is insufficient existing data to allow modelling corrosion by HSSs.

Bicine appears to show up in DEA and secondary amine systems subject to oxygen contamination when treating CO<sub>2</sub> only, or with systems containing very low H<sub>2</sub>S concentrations in the feed. When H<sub>2</sub>S is present at significant concentrations in the feed gas, oxygen is expected to be scavenged effectively by reaction with the residual H<sub>2</sub>S present as lean loading to make the HSS, thiosulfate. Bosen and Bedell ran corrosion simulations which suggested that the presence of H<sub>2</sub>S in the amine at as little as 10 ppm could eliminate the chelation concerns of bicine.<sup>5</sup>

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# A DEEP DIVE INTO THE USE CASES OF THERMAL SPRAY APPLICATIONS



**Colin Bateman, Integrated Global Services (IGS), UK**, explains the lessons that can be learned from use cases of thermal spray applications in process vessels and columns.

**W**hen faced with metal wastage, asset owners and operators can address the corrosion mechanisms with a corrosion-resistant alloy (CRA) barrier.

The technique used to apply this CRA will mainly be determined by the shutdown time available to carry out the application.

While weld metal overlay remains a reliable option, laboratory testing and performance validation, field application, and subsequent site inspections of high velocity thermal spray (HVTS) alloy cladding projects have confirmed this solution to perform 'in the same league' with several added benefits.



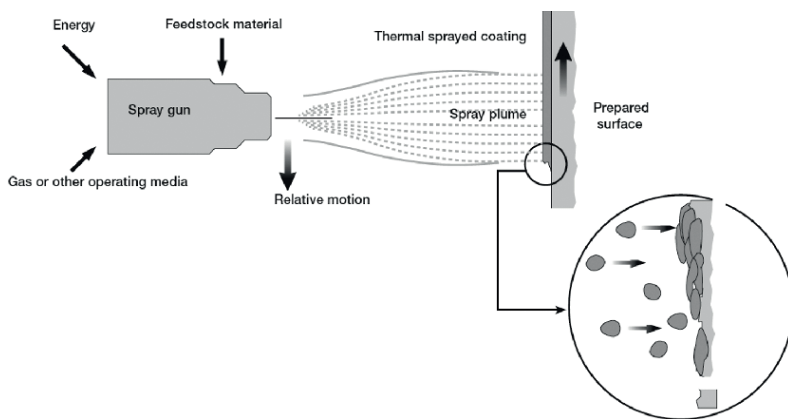
## The evolution of HVTS

Thermal spray technology has been utilised for the application of CRA since the 1980s, spraying metals widely used for corrosion protection. However, it was quickly noted that the thermal spray process itself (Figure 1) can negatively affect the condition of the material being sprayed. The resulting cladding, when using traditional metal alloys and commercially available thermal spray equipment, has not been able to create a sufficient barrier to corrosive media.

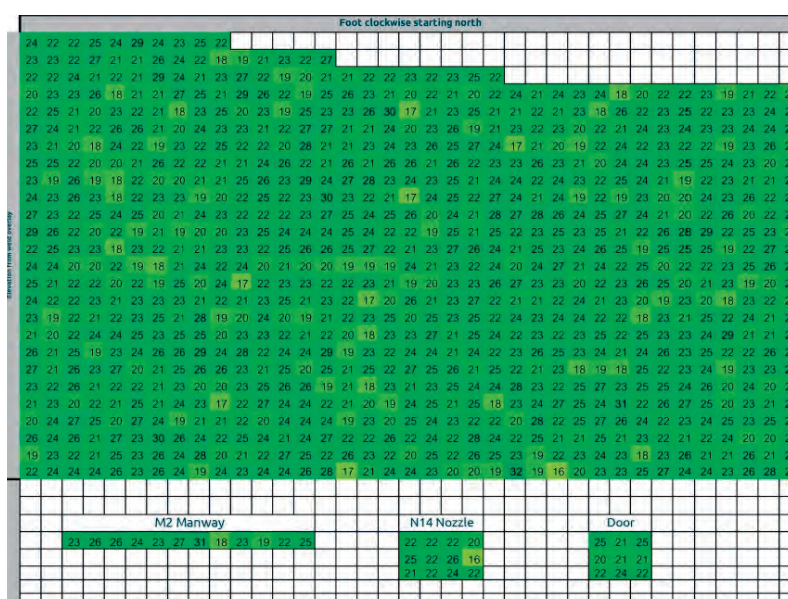
Permeability, coupled with internal stress and lower bond strength with the base metal, creates a path for corrosion and premature failure. These early failures resulted in an understandable, and rather universal, distrust of early iterations of commercially available thermal spray technology.

## Engineering a solution

Engineers and material scientists have successfully developed a solution to this problem by redesigning the equipment used to apply the metal cladding, the



**Figure 1.** An illustration of the thermal spray process.



**Figure 2.** IGS HVTS thickness mapping.

process technology, and the alloy of the feedstock material.

## True high velocity

The atomisation velocity is a critical success factor in thermal spray cladding for critical equipment liquid and gas corrosion environments. For thermal spray cladding applied with a wire feed stock, a high velocity process is defined where the material atomisation occurs in a super-sonic gas stream (gas stream velocity equal to or greater than Mach 1), which results in specific particle characteristics critical to achieving an impermeable barrier.

## Creating an impermeable barrier

As particles are ejected from the thermal spray torch at high temperature and velocity, they are exposed to air with a high nitrogen and oxygen content. The molten particles are inclined to rapidly oxidise in flight. On deposition, oxide bands are formed in layers, along with the metal splats.

These oxide structures constitute permeable pathways through the applied thermal spray and are to be avoided in any application, especially where corrosion is present. Chemical and process controls are employed to significantly inhibit in-flight oxide formation.

## Bond strength

The problem of bond strength, both between the applied metal particles and the substrate, was solved by increasing velocity and improving the quality of the substrate surface preparation. When the molten metal particles hit the substrate with a suitable profile at speeds close to supersonic, they splat and embed metal into the substrate, forming tight bonds. The particles themselves do not have a perfectly smooth microstructure; this feature promotes good intersplat adhesion. Multiple additional overlapping passes of the thermal spray torch then create a 500 µm thick cladding with excellent adhesion throughout (Figure 2). ASTM adhesion pull-off tests measure bond strengths of 30 - 60 MPa.

## Case study 1: fixing failed low velocity thermal spray coatings

### The problem

A US refinery identified a problem with its second stage desalter and overhead accumulator vessels during a routine inspection.

A nickel-copper thermal spray coating had been applied in both vessels



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**Table 1. A technical comparison of HVTS, weld overlay and organic coatings**

	IGS HVTS	Weld overlay (WOL)	Organic coating (non-metallic)
Corrosion resistance	Yes	Yes	Yes (temperature and organic material dependent)
Erosion resistance	Yes	Medium (depending on alloy)	Temperature and organic material dependent
Typical alloys utilised	Modified 625 alloy, C-276 hastelloy and monel alloys	316, 625, 622, 52, monel, hastelloy with iron dilution	N/A
Bond	Mechanical and chemical (>35 MPa)	Metallurgical	Mechanical and chemical (>15 MPa)
Typical thickness specification	500 µm nominal	2 - 3 mm (dilution issue below 2 mm)	
Post-weld heat treatment (PWHT) requirement	No	Yes (required for most applications or HAZ becomes weak corrosion resistance area)	No
Dilution into base material	No	Yes	No
Heat affected zone (HAZ)	No	Yes	No
Stress/distortion of base material	No	Yes	No
Application speed	3 - 6 m <sup>2</sup> /shift/machine	0.5 - 2 m <sup>2</sup> /shift/machine	5 - 10 m <sup>2</sup> /shift/gun + variable curing time
Repairability	Blast preparation, build up and/or reapply locally	Blast preparation, grind and reweld if not cracked/contaminated locally possible	Blast, surface preparation and re-application
Replacement/removal	Possible aggressive blast removal	Grind-out for removal	Locally impossible aggressive blast removal
Durability	Metallic cladding – mechanically tough and temperature resistant	Metallic cladding – mechanically tough	Organic coating – fragile and susceptible to damage mechanically or by heat
Steam out resistance	Yes	Yes	No
Thermal resistance	Metallic cladding – high temperature capability (>500°C)	Metallic cladding – high temperature capability (>500°C)	Organic coating – fragile and susceptible to damage mechanically or by heat
Curing requirements	Metallic cladding – no cure	Metallic cladding – no cure	Organic coating – chemical reaction required to cure organic systems (cure rate dependent upon environmental condition)
Application requirements	Metallic cladding – minimum environmental control required	Metallic cladding – minimum environmental control required	Organic coating – strict environmental controls required (temperature, humidity, surface salts, amine bloom, solvent release, etc.)
External inspection capability	Yes	Yes	No

approximately 20 years ago. Initially, the coating performed as expected. However, after some time, localised damage was evident on the bottom third of both vessels, leading to deep pitting and metal wastage beyond the existing corrosion allowance.

### Thermal spray coating and weld failures

Typical thermal spray coatings are not suitable for internal protection of mission critical process equipment due to their permeability, weaker bond strength and propensity to cracking. These 'low velocity' thermal spray systems cannot produce flat and tightly packed particle sizes or nano-scale grain structures, leading to the coating's failure due to corrosion and/or permeation.

Furthermore, weld repairs were also attempted, adjacent to the failing thermal spray, and a crack had formed on its heat affected zone (HAZ). In 2017, refinery engineers decided they needed a more permanent solution.

### The solution

A HVTS alloy cladding solution was chosen to prevent corrosion for the expected life of the asset, with no further maintenance anticipated for at least the next 15+ years.

HVTS technology utilises alloy materials, which offer erosion-corrosion protection, even in high-temperature and high-pressure service up to 1371°C (2500°F) (Figure 3).

The cladding option also offered significant time savings compared with weld overlay. As a result, the refinery project manager welcomed the solution, and HVTS was applied in spring 2019.

The bottom third of the overhead accumulator, including the stem pipe with a



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vortex breaker and a flange, were protected with HVTS. Regular inspections have shown no deterioration of the cladding since application.

## Key benefits of HVTS

### Robust

HVTS is considered more robust than organic coatings for several reasons. Firstly, HVTS relies on mechanical bonding to the substrate – molten particles are propelled at high velocities creating a bond that is inherently stronger than the adhesive bond typical with organic coatings.

Furthermore, HVTS has a higher immersion temperature resistance, which means it is often chosen for applications involving immersion in aggressive substances. Its resistance to immersion at elevated temperatures surpasses that of organic coatings, which may experience degradation or chemical breakdown when exposed to corrosive liquids or gases.

For example, TCO in Kazakhstan holds 26 billion bbl of oil and gas and has a high sour gas (hydrogen sulfide [H<sub>2</sub>S]) content of about 6%. The plant identified major corrosion and process vessel integrity issues due to earlier applications of organic coatings. These coatings are often solvent-based, and in these instances, apart from other limitations, problems are experienced due to solvent retention within the film. This retained solvent will then increase in volume as it is exposed to higher temperatures, which in turn leads to blistering.

In contrast, the robustness of HVTS compared to organic coatings can also be attributed to its hardness, temperature resistance, flexibility in thickness and resilience to mechanical and chemical stresses.

### Cost-effective

HVTS offers several cost-effective advantages over traditional weld overlay methods, such as reduced downtime and faster application.

It has a faster application process compared to weld overlay. Traditional weld overlay involves time-consuming welding procedures, which may require the shutdown of equipment or entire facilities. In contrast, HVTS can be applied more rapidly, minimising downtime, and allowing for quicker return to service. The efficiency of the application process contributes to overall cost savings by reducing the impact on production schedules and operational continuity.

Weld overlay introduces HAZs in the substrate material due to the welding process. These zones can experience changes in metallurgical properties, potentially leading to issues such as reduced material strength or increased susceptibility to corrosion. HVTS, being a thermal spray process, does not generate HAZ. This eliminates the need for post-weld heat treatment and reduces the risk of material degradation, simplifying the overall process and reducing associated costs.

Other factors that make HVTS a more cost-effective option include lower equipment and labour costs, material savings, and the elimination of post-weld inspections.

## Case study 2

A multinational oil and gas company has been focusing on meeting the world's growing energy needs while reducing its carbon emissions intensity. As a result, it converted one of its refineries to a renewable fuels manufacturing and terminal facility, capable of producing approximately 730 million gal./yr of renewable fuels.

### The problem

A low-pressure separator with minimum corrosion allowance remaining was being prepared for renewable diesel conversion to mitigate the risk of carbonic acid attack in the new operating environment. The plant considered welding internal cladding, but that option carried significant costs and would require 30 shifts to apply.

### The solution

The plant selected HVTS to upgrade the metallurgy of the separator to a higher nobility alloy, able to prevent carbonic acid corrosion. References, operational excellence, and the ability to inspect the separator in between turnarounds without shutting it down were the key drivers for this decision. The application cost 50% less than weld metal overlay would have cost and was applied in one-third of the time.

## Case study 3

A recent ESG case study conducted by IGS shows a breakdown of the oil and gas projects that IGS has completed since 2012. Looking at the statistics of 1354 projects, with an average scope of 680 ft<sup>2</sup> each, for only the past 11 years the following calculation can be done to determine the amount of CO<sub>2</sub> that would potentially have been released into the atmosphere if those vessels had to be replaced:

$$26\,301 \frac{\text{kgCO}_2}{\text{year}} - 5\,884 \frac{\text{kgCO}_2}{\text{year}} = 20\,417 \frac{\text{kgCO}_2}{\text{year}}$$

$$= 20\,417 \frac{\text{kgCO}_2}{\text{year}} \times 11 \text{ years} = 224\,587 \text{ kgCO}_2$$

$$224\,587 \text{ kgCO}_2 \times 1354 \text{ vessels} = 304.09 \text{ million kgCO}_2 = 304\,009 \text{ tonCO}_2$$

304 090 t of CO<sub>2</sub> is equivalent to 703 340 bbl of oil consumed or 340 627 459 lbs of coal burned.

## ESG considerations

HVTS is considered advantageous for environmental, social, and governance (ESG) objectives due to its specific characteristics and performance attributes, including the following:

### Reduced environmental impact

The application of HVTS often involves fewer environmental concerns compared to alternative methods such as traditional weld overlay.



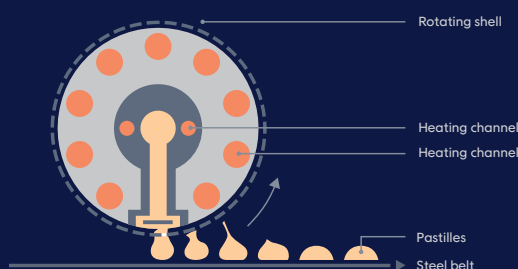


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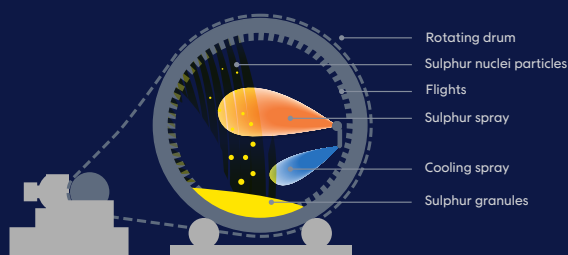


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**Figure 3.** A technician applying HVTS cladding to a substrate.

HVTS typically generates fewer emissions and requires less energy during the application process, contributing to a lower overall environmental footprint.

#### ESG reporting and compliance

Utilising HVTS for corrosion protection aligns with ESG reporting and compliance requirements. Organisations that adopt technologies with environmental benefits, such as HVTS, can


demonstrate a commitment to sustainability in their reporting and contribute to a positive ESG score.

#### Long-term sustainability

HVTS coatings are designed for durability, providing long-term protection against corrosion. This longevity aligns with sustainability goals by reducing the frequency of coating applications and associated resource consumption over the asset's lifecycle.

#### Conclusion

In the ever-evolving landscape of corrosion mitigation technologies, the journey from traditional methods to advanced solutions, such as HVTS, has been transformative. When navigating the lessons learned from thermal spray applications in process vessels and columns, a clear narrative emerges – one of innovation, quality standards, and sustainable practices.

CRA technologies signify a commitment to a future where corrosion mitigation goes hand-in-hand with environmental responsibility and operational efficiency. With each use case, HVTS reinforces its role as a cornerstone in the pursuit of a corrosion-free, sustainable industrial landscape. 

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# A technical review of ENAP's Aconcagua refinery sulfur block – part one

In part one of this article, **Marco van Son, Ines Hernandez-Virla and Frank Bela, Worley Comprimo, alongside Xavier Pizarro, Sebastian Chaparro and Carmen Rodriguez, ENAP**, discuss the findings of Worley's technical review of the sulfur units at ENAP's Aconcagua refinery.

**T**he Aconcagua Refinery (ERA) in Chile is one of three refineries owned by the Empresa Nacional del Petróleo (ENAP). It has a processing capacity of 15 000 m<sup>3</sup>/d of crude oil (100 000 bpd) distributed in two primary and vacuum distillation units. In its configuration, the refinery has different hydrotreaters, two mild hydrocracking (MHC) units, a fluid catalytic cracking unit (FCC) and a delayed coker unit (DCU), among other process units.

The sour components produced in these units are processed in the following units:

- Sulfur recovery units (SRUs) 1, 2 and 3 (URA1, URA2 and URA3).
- Sour water stripper units 1 and 2 (SWS1, SWS2).
- Amine units (U500, U300, U950, U1700, U1800, U3000, U3200).

As of 2019, Chilean environmental regulations have undergone a series of modifications that have tightened the operation of the SRUs and their associated units. In order to be able to monitor these emissions, continuous emissions monitoring systems (CEMS) have been installed in all three URAs.

Before these new regulations were introduced, the allowable quantity of sulfur (SO<sub>2</sub>) emissions was 2190 tpy. However, since 2019, the regulations have established a decreasing limit with a target of 1145 tpy for 2023 (a reduction of 50%). Figure 1 shows the annual emissions limits.

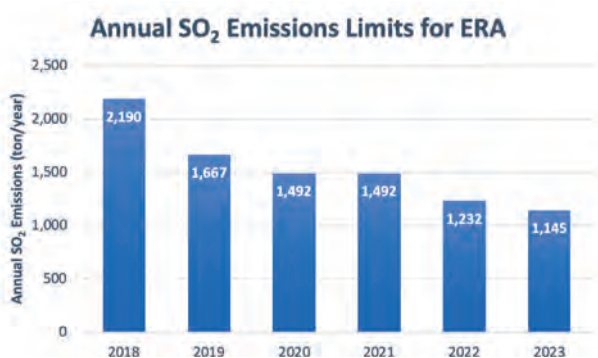
Moreover, during 2020 - 2021, the availability of the sulfur treatment system decreased considerably as a result of operational problems, load instability, maintenance shutdowns, early equipment and instrumentation failures, etc.





To investigate the causes of these increased emissions, as well as the reduced availability of the units, ENAP contracted Comprimo, part of the Worley organisation, to carry out an external technical review. This allowed a diagnosis of the system as a whole and made it possible to define short, medium and long-term plans to ensure the reliability of the units, maintaining their availability and compliance with current environmental regulations.

The technical review consisted of two one-week site visits, an operator questionnaire to evaluate the current knowledge of the design and operation of the environmental units, and a number of presentations and meetings to review past and current problems.



**Figure 1.** Aconcagua allowable emissions.



**Figure 2.** URA2 tail gas piping tracing.

Comprimo prepared worksheets for each individual unit, as well as general worksheets that encompassed multiple units to provide recommendations for physical and operational changes. The worksheets outlined which aspects of the plant were impacted, as well as the severity of the current deficiency of the facility. The impact to the plant was segregated into the following categories:

- Efficiency = emissions.
- Reliability = risk of failure of equipment or instrumentation.
- Production = impact on total production of the refinery.
- Safety = protection of personnel and the public from harm.

The severity of the worksheets was divided into the following categories:

- Critical: consists of mitigation measures that must be implemented as soon as possible.
- High: consists of mitigation measures that must be implemented during the next plant shutdown in a planned manner.
- Medium: measures that would improve the current performance, but are not fundamental to the plant's operations.

## Plant description

### SRUs

URA1 was designed in 1994, initially with a capacity of 30 tpd and 96.5% sulfur recovery from amine acid gas (AAG) containing 82 mol % hydrogen sulfide (H<sub>2</sub>S). Design was subsequently modified to also process a substantial amount of sour water acid gas (SWAG), while reducing the AAG based on maintaining original total air demand. SWAG accounted for 60% of total H<sub>2</sub>S, reducing sulfur production capacity to 20 tpd. The unit was commissioned in 1994.

URA2 is a 2+1 EUROCLAUS unit, designed by Comprimo in 2002 as a 2+1 SUPERCLAUS unit, and converted to EUROCLAUS in 2016. The unit was designed with a capacity of 45 tpd and 99.1% sulfur recovery, processing AAG with a H<sub>2</sub>S content of 82 mol% and SWAG containing 25 mol% H<sub>2</sub>S and 25 mol% NH<sub>3</sub>.

URA3 is a 3+1 EUROCLAUS unit designed by Comprimo in 2006. The unit was designed with a capacity of 45 tpd and 99.3% sulfur recovery, processing AAG with an H<sub>2</sub>S content of 90 mol% and SWAG containing 28 mol% H<sub>2</sub>S and 38 mol% NH<sub>3</sub>.

## Technical review

### Field review

The first step in the review of the units in the sulfur complex was to walk through the plant to determine whether there were any initial indicators of potential issues with the units during operation. This also included discussions with operations about operating modes that could lead to potential problems with emissions.

### Plant heating

Plant heating appeared to be a major concern in the facility. It is critical that the following systems are properly heat maintained:

- SWAG – maintain wall temperature and all instruments above 75°C (167°F).
- Sulfur lines – maintain wall temperatures and all instruments above 125°C (257°F).



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- Vapour lines containing sulfur – maintain wall temperatures and all instruments above 125°C (257°F). (This only applies for systems with normal temperatures below 140°C (284°F) and systems that can have stagnant flow.)

The heat maintenance of a system heavily depends on the following four factors:

- Type of tracing: tube tracing, bolt-on jacketing, jacketing.
- Pressure and quality of the steam supplied to the tracing.
- Type and maintenance of the steam traps installed.
- Condensate back pressure.

A portion of the SWAG lines, as well as the vapour lines containing sulfur, appear to be traced with 0.75 in. or 1 in. pipe tracers, which, depending on the line size, may have 2 - 6 tracers often with sections of insulation missing or no insulation at all on flanges. An example of this can be seen in Figures 2 and 3. Most of these tracers did not touch the piping to provide direct conductivity of heat from the tracer to the pipe wall. Most of the interconnecting SWAG piping between the sour water strippers and SRUs was jacketed. However, due to failed welds, the plant no longer kept the acid gas piping



**Figure 3.** Tracing of vent gas piping including unheated pipe support.



**Figure 4.** Bolt-on jacketing for flanges.

hot, resulting in substantial corrosion in the interconnecting piping.

Flanges in these services act like very large heat sinks and must also be traced. In practice, it is not possible to get good contact between a tracer and the flange, and it is therefore recommended to install bolt-on jackets onto the flanges as shown in Figure 4, which must be insulated. Several examples were found in the plant where these were installed, however the majority of the flanges in SWAG and sulfur vapour service were found to be exposed to the atmospheric conditions.

It should be noted that in Figure 4, the 1 in. pipe tracer does not touch the pipe, making the heating very inefficient. This vent line from the pit is likely plugged with solid sulfur.

## Operational review

### URA2 operation

URA2 appeared to have been an ongoing problem at the refinery with respect to emissions. Due to agreements with the government, the EUROCLAUS® selective oxidation catalyst was replaced in this unit every six months for several years. This meant that every six months the fresh catalyst needed to be conditioned, which is also a period of higher emissions for the refinery. During the conditioning, URA2 operates at a reduced sulfur recovery efficiency, requires operation with only AAG for approximately 5 - 7 days, and requires the full attention of the board operators to monitor the progress of the conditioning. It is Comprimo's experience that the catalyst typically lasts between 5 - 8 years and there have been cases of more than 10 years of operation with a single batch.

Upon review of the operating conditions, as well as the results from samples taken downstream of the coalescer, it was found that the typical emissions from the stack of URA2 were in the order of 2500 ppm of SO<sub>2</sub> and that the yield of the EUROCLAUS selective oxidation catalyst was below 70%, an indication of the deactivation of the catalyst.

Comprimo monitored the operation of URA2 between 24 May 2022 and 6 June 2022.

There were two items that stood out during this period that merit further discussion.

Firstly, there appeared to be a preferential temperature rise on one side of the third reactor, as well as a temperature drop in the bottom of the reactor on one side. The temperatures in the reactor are shown in Table 1.

This is not normal for a selective oxidation reactor as the temperature rise is always steady from the top to the bottom. With a properly installed and conditioned catalyst, there should be little difference in temperature profile between the two sides of the reactor.

Secondly, on 4 May 2022, URA2 experienced a trip of the unit caused by a low AAG flow. An interesting observation was made from the unit trip: after the unit was returned to normal operation, the severe preferential temperature rise on the right side of the reactor was no longer present, and it appeared that the temperature rise occurred equally on both sides of the reactor (Table 2).

At the same time, the emissions from URA2 dropped from over 2000 ppm to less than 1500 ppm, indicating a dramatic improvement of the performance of the third reactor.



During the trip, the blowers also tripped, resulting in the absence of air to the reactor while the reactor was in bypass operation.

This improvement in performance was not sustained and after approximately 10 days, the temperature difference between the left and right side started to occur again, becoming progressively worse. In the month after the URA2 trip, the bottom temperature rose from about 270°C to 300°C, consistent with a decrease in selectivity of the catalyst. In addition, it appeared that the temperature in the middle right side of the reactor was again higher than the bottom right side.

Several other observations were also made at that time:

- The sulfur flow from the third sulfur condenser was lower than the sulfur flow from the fourth sulfur condenser. This is unusual as the sulfur production decreases in subsequent sulfur condensers in a 2+1 EUROCLAUS unit.
- The sulfur rundown, including the sulfur boot from the third condenser, was opened and checked for plugging and no evidence of plugging was observed in the rundown piping.
- A sulfur flush was performed, which did not appear to improve the sulfur flow.
- There was sulfur coming out of the demister box (see Figure 5).

Based on all of this evidence, Comprimo had strong suspicions that the poor performance of the catalyst in the

**Table 1. Temperatures in the reactor before trip**

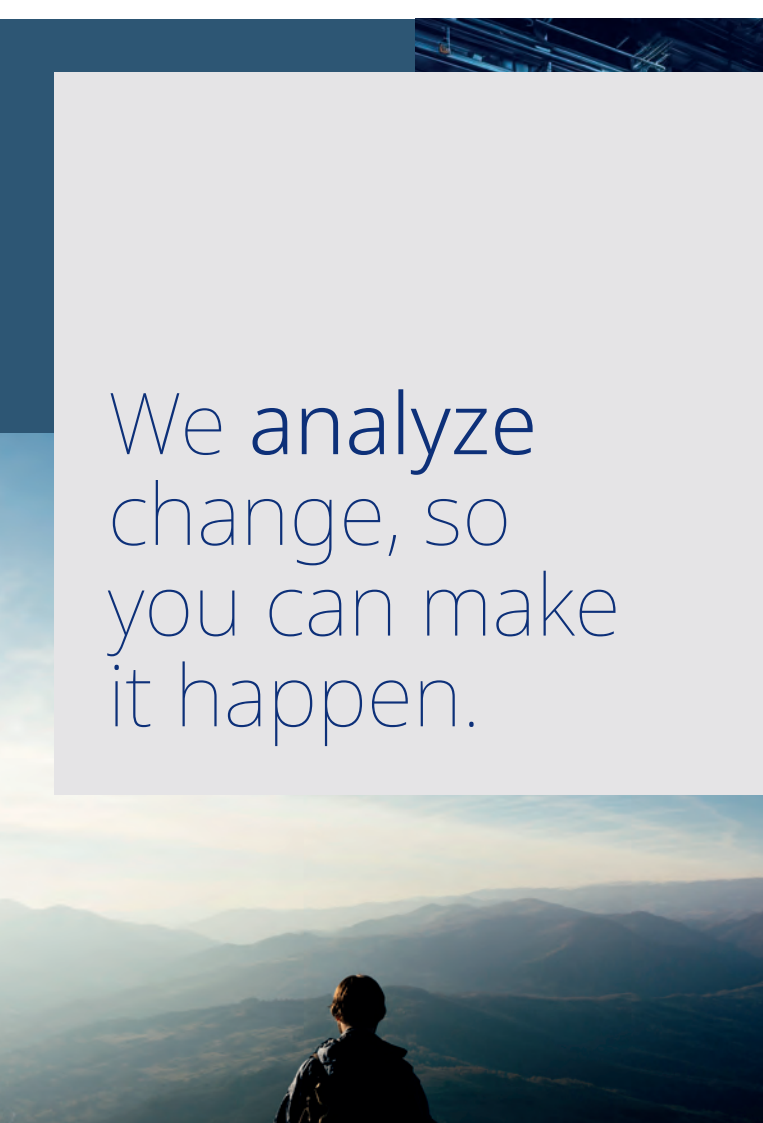
	Left	Right
Top	199.6°C	225.2°C
Middle	267.4°C	300.3°C
Bottom	275.3°C	292.0°C

**Table 2. Temperatures in the reactor after trip**

	Left	Right
Top	195°C	195°C
Middle	245°C	260°C
Bottom	270°C	270°C

URA2 third reactor was caused by continuous sulfur carryover from the third condenser. As the rundown appeared to be open, Comprimo believed that the sulfur carryover was caused by a partial blockage of the sulfur outlet nozzle in the outlet channel, potentially caused by a collapsed demister.

The effect of this sulfur carrying over to the third reactor was that on one side of the catalyst, the sulfur blocked the active sites, and continuously flowed slowly down the catalyst. As a result, the performance was poor and also potentially caused some Claus activity across the catalyst due to the presence of liquid sulfur. Due to the heat of vaporisation of the liquid sulfur flowing down the catalyst, a temperature decrease in the bottom of the reactor was observed. In addition, the sulfur carryover also explained the



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**Figure 5.** Evidence of sulfur from the demister box in URA2 Third Condenser C-1644.

higher sulfur flow from the fourth sulfur seal, compared to the flow from the third seal.

## Conclusions

Comprimo performed a thorough technical review of the sulfur complex at the ENAP Aconcagua refinery to determine what design, operations and maintenance practices could be limiting its ability to meet processing run lengths and environmental targets on a continuous basis.

The review provided ENAP with a better understanding of the design limitations of its existing units, and how it could operate to ensure it was meeting required emissions targets set by the government. Comprimo provided clear key performance indicators (KPIs) for all of the units, which will allow the operators to maintain the units within the recommended operating limitations, thereby maintaining better performance and longer life.

One of the main conclusions of the review was a lack of understanding of the importance of proper heating of the piping and equipment in a sulfur plant. It is essential to have the design of the heating system of a sulfur recovery carried out by an experienced company that is well-versed in the calculation of heat losses in a system where sulfur freezes below 120 °C (248°F).

In part two of this article, Comprimo and ENAP will discuss the findings during their most recent turnaround of URA2 and outline how this improved the overall emissions from the refinery's sulfur block. [\[1\]](#)

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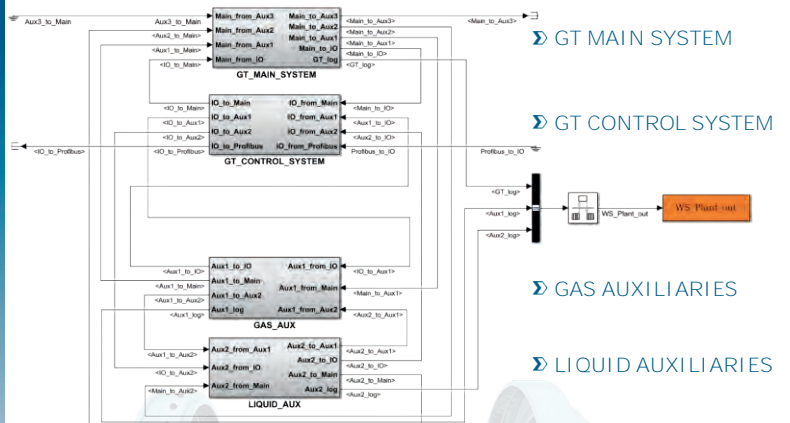
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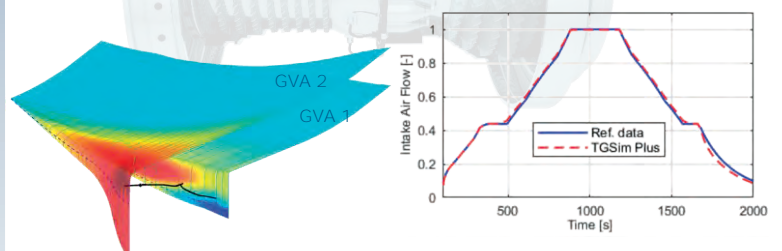
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# Optimising PROCESS FLUIDS

**Mike Strobel, Swagelok**, explores how Raman analysers can provide meaningful insights into how process fluids are performing in chemical plants and refineries.

One of the most important responsibilities for chemical plant and refinery operators is providing their team with accurate process analysis. The more information gathered about process fluids, the better they can be controlled (Figure 1).

Operators must use the right process analyser to gather accurate information, and Raman analysers are one such technology. Though they are relatively new tools that use Raman spectroscopy to analyse the fluids, these analysers are some of the most effective process analysers on the market.

## What is a Raman analyser?

Raman analysers rely on measuring how light scatters when shined through a process fluid. Nearly 100 years old, the use of Raman analysers was initially considered impractical due to the absence of a strong enough light source, leading to Raman scattering that paled in comparison to Rayleigh scattering and proved challenging to measure.

Originally, the Raman scattering process used mercury lamps to produce monochromatic radiation, but the analysis method did not become popular among fluid engineers until the 1960s when laser lights were introduced into the process. The intensity of lasers and their ability to focus on a small sample meant smaller concentrations could provide superior spectra.

The final piece of the puzzle was found when charge-coupled device (CCD) detectors were added to the process. These detectors were able to pick up the weaker

Raman signal and make it more visible to the operators. With the advent of CCD detectors, Raman analysis became more commonly used in the 1980s and thereafter.

## How do they work?

Unlike other analytical techniques, Raman analysis does not destroy the sample and offers detailed insights into the chemical composition of the liquid, solid, or gas sample (Figure 2). An operator points a monochromatic laser in the visible, near infrared, or near ultraviolet range at the sample, which causes molecules of the liquid, solid, or gas to move from a ground vibrational state to a virtual vibrational state.

When this occurs, light scatters both elastically and inelastically. The former, also known as Rayleigh scattering, means the released light contains the same amount of energy as the incident light photons. The latter, known as Raman scattering, happens in one of two ways:

- A molecule moves to a virtual state and retains some of the energy absorbed from the initial light source, meaning the scattered light has slightly less energy than the incident photon and a longer wavelength.
- A molecule already in a higher vibrational state returns to its resting state after interacting with the light and the emitted photon has a higher energy (shorter wavelength) than the incident photon.

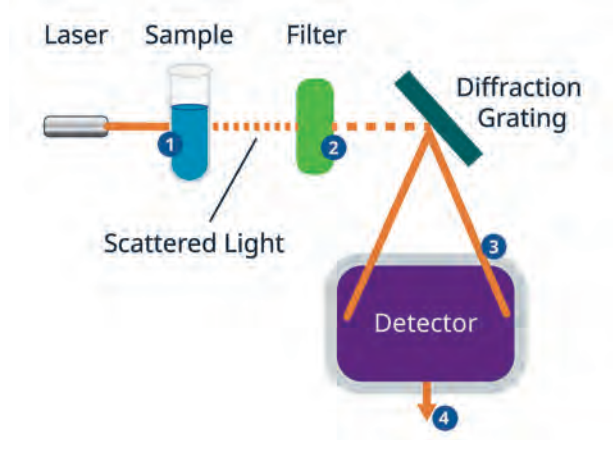
Although there are many kinds of Raman analysers, only two make sense as process analysis tools. The most



common is called Raman spectroscopy, described above. The produced spectrum – the Raman spectrum – is often called the Raman fingerprint in scientific literature. Like human



**Figure 1.** Chemical plants and refineries must continually validate process conditions and fluid compositions to ensure quality control throughout their facilities.



**Figure 2.** This visualisation of the Raman sample analysis process highlights the following steps: 1. The laser illuminates the sample. 2. The Raman analyser filters out Rayleigh light scattering. 3. The Raman-scattered light enters the detector for measurement. 4. The Raman fingerprint is assigned a value.



**Figure 3.** Consulting with a reliable supplier can help plant owners evaluate their quality control needs and determine the best locations throughout a plant to perform process analyses.

fingerprints, no two Raman fingerprints are alike. They are assigned a value, or values based on mathematical models specific to the application.

The baselines may be generated in a lab, but most manufacturers produce theoretical models to keep implementation times shorter. It should be noted that careful modelling and proper application of the resulting models are crucial to producing an accurate Raman measurement.

## Advantages

Raman spectroscopy allows operators to monitor process health continuously and can verify the substances' chemical composition at each state. This allows operators to have a detailed understanding of whether systems are operating at peak performance. Based on this comprehensive analysis, decisions about how to adjust processes can be made more quickly, minimising rework and waste. Additionally, it is possible to use Raman spectroscopy to ensure products coming off the line are properly constructed to minimise reprocessing.

Additional operational benefits include:

- Little to no sample conditioning required, helping to reduce startup and ongoing maintenance costs.
- Minimal to no sample transport time, greatly reducing time delays and providing a nearly real-time analysis.
- No manual calibration required.
- Minimal maintenance needs over the course of their lifetime, allowing you to focus labour on other tasks.

## Disadvantages

One of the most significant disadvantages of Raman analysers is that they depend on modelling, which means results depend on the quality of the model. Gas mixture components are easily differentiated in linear regression analysis, but liquid analysis is much more challenging. The development of liquid models can take months or even years, which can delay implementation and also costs more upfront.

In addition, Raman spectrometers are not as precise as other analysis methods. Their lack of sensitivity means they can only measure down to a few hundred ppm, which is less useful in cases where exacting precision is required.

## Common applications

Despite these potential shortcomings, Raman spectrometers are ideal for a number of industrial system applications:

### Gasoline blending

Octane rating, boiling points, and Reid vapour pressure (RVP) can all be effectively measured using Raman spectroscopy in gasoline blending. With fast response and accurate analysis, operators can, for example, maintain the optimal octane rating of their final product while minimising giveaway.

### Natural gas quality measurement

Hydrocarbon components in natural gas can vary from only trace amounts to nearly 100% of the mixture. Inert gases present in the natural gas mixture can reduce its energy density, and therefore its value. Raman spectroscopy is a good choice for fast and accurate natural gas measurement as it does not require separation of the components like the traditional gas chromatography method.



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## Hydrotreating and hydrocracking

Hydrogen is of critical importance in these refining operations. Raman spectroscopy is a good solution when a full composition analysis is required. After a pressure swing absorption unit, real-time Raman analysis can help operators ensure proper hydrogen removal before suboptimal product has flowed downstream. Additionally, Raman spectrometers can generally measure at higher pressures than other methods. This increases the likelihood of returning the fluid to process rather than flare, helping to reduce operating costs.

## Drilling exploration

Optimising the drilling process and supporting safety for operators is critical as drillers search for oil and gas reserves. Increasing drilling speeds requires faster measurement response that cannot be achieved by traditional measurement technologies, such as gas chromatography. The Raman spectrometer's ability to simultaneously measure both hydrocarbon and nonhydrocarbon molecules also decreases the need for additional analytical instrumentation.

## Mud logging

Mud logging is the measurement and cataloguing of rock cuttings, mud, and gases that are driven to the surface during borehole drilling. Monitoring the composition and characteristics of the mud is critical to optimise the drilling process and check that an explosive mixture of gases is not present. The continuous monitoring provided by the Raman

spectrometer helps operators make informed decisions that increase efficiency and help maintain operator safety.


## Measuring fuel gas in a refinery

Refinery fuel gas, which typically occurs when natural gas and recovered flare gas are combined, offers an opportunity to use a Raman spectrometer to stay abreast of its chemical composition.

Fuel gas quality can vary widely because the recovered flare gas differs in composition, which can lead to lower efficiencies in equipment using fuel gas as a primary source of energy. Boilers in particular may experience unstable flames if hydrogen levels spike within the fuel gas mixture.

Since Raman analysers can measure hydrogen content quickly, close monitoring keeps the levels within the range necessary to fuel the machines. If the hydrogen spikes above acceptable levels, operators can quickly implement changes to avoid damaging process equipment and keep the operation running smoothly over time.

## The bottom line

Depending on the specific application, it may be beneficial to use Raman process analysers in refineries or chemical plants to keep things running efficiently. To ensure they are the right analysers, it is crucial to work with a qualified supplier who can guide decision-making. This will enable operators to decide which technologies are most effective to analyse industrial fluids and keep businesses running predictably and profitably (Figure 3). 



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# Unveiling the potential of heat pumps

**Jörg Freckmann and Dr. Lothar Wallscheid, MAN Energy Solutions,** reveal how industrial heat pumps can be used to decarbonise process steam supply.

**A**ccounting for 50% of global final energy consumption, heat is the largest energy end-use and contributes to 40% of global carbon dioxide (CO<sub>2</sub>) emissions. Approximately 50% of total heat produced is used for industrial processes, while another 46% is consumed in buildings for space and water heating and, to a lesser extent, for cooking, with the remainder used in

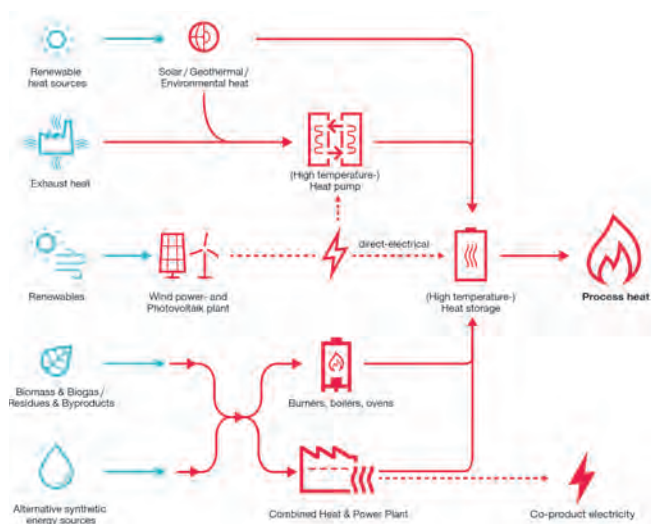
areas such as agriculture, predominantly for greenhouse heating. Despite modern renewable energy sources, fossil fuels continue to dominate heat supplies.

Geopolitical factors, associated scarcity of raw materials at high costs, and CO<sub>2</sub> pricing, particularly in Europe, are major drivers for ramping up the electrification of industrial processes based on renewable energy sources.

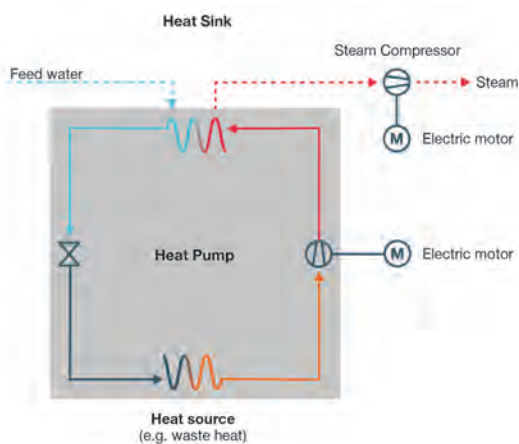
Therefore, the limited fossil raw materials need to be used as feedstock for the production process, instead of being wasted on process heat production.

Considering this context, decarbonisation and re-electrification (power-to-heat) of industrial processes have gained significance, offering a high potential for waste heat utilisation. Heat pumps will play a crucial role in converting low and high temperature waste heat into useful high quality process heat (steam or hot water).

Moreover, the resilience of the energy system is affected by the availability of renewable energy sources such as photovoltaic (PV), wind, etc. During periods of surplus renewable energy, the operating state of heat pumps can be adjusted to draw additional power from the grid, aiding grid frequency control and stability. The storage capacity of the system connected to the heat pump must be taken into account in such cases. Switching between temperature and grid frequency-controlled operation can present an additional business opportunity for the heat pump operator if the grid operator charges for this service.



**Figure 1.** Decarbonised process steam production, technologies and energy sources (<sup>2</sup>adapted).



**Figure 2.** Steam production with heat pump (SPHP) and additional steam compression (SC).

Conversely, controlled load shedding during periods of excessive grid load may also be of interest to the grid operator.

## Industrial applications

Heat pumps are well known for their application in urban settings, whether for decentralised or centralised heating of buildings, and their usage is expected to expand significantly with the ongoing decarbonisation of heat supply. In 1938, the installation of the first heat pump (with a thermal power output of 100 kW) at the City Hall in Zurich, Switzerland, by the company, Escher Wyss, was a groundbreaking achievement.<sup>1</sup>

The largest addressable industrial segments for heat pumps are the chemical and petrochemical, pulp and paper, and food and beverage sectors. Medium to large plants in these segments exhibit high potential for large-scale industrial high-temperature heat pumps, offering heat (hot water or steam) for multiple processes. Particularly, the chemical/petrochemical sector – the largest industrial energy consumer and the third-largest industry segment in terms of direct CO<sub>2</sub> emissions – is making substantial efforts to reduce greenhouse gas (GHG) emissions. Global chemical and petrochemical producers are planning a long-term transition to achieve net zero CO<sub>2</sub> emissions (by 2050 at the latest). This will be accomplished by:

- Improving efficiency to limit the need for energy and/or resources to produce a desired product.
- Operating combined heat and power plants and heating boilers with low-carbon fuels, such as biogas or sustainable hydrogen, instead of natural gas or other fossil fuels.
- Implementing new process technologies that replace fossil fuels (including natural gas) with electricity derived from renewable sources (power-to-heat).

Figure 1 details energy sources and technologies facilitating carbon-neutral process heat generation.

The most effective and efficient approach to achieving climate goals involves implementing power-to-heat technologies, specifically the integration of industrial high-temperature heat pumps in chemical and petrochemical production processes.

In comparison to district heating, the chemical industry typically requires higher temperatures. These processes are usually served by conventional steam boilers, which can be replaced by industrial heat pumps unless the process provides exothermic heat. The main application lies in generating steam at different pressure levels according to individual process requirements.

## Steam production: the future with heat pump technology

Heat pump solutions efficiently convert heat sources (ambient or waste heat) into usable energy. One of their main advantages, in comparison to electrical boilers, is their ability to produce more heat output than electrical energy consumed.

Process steam can be generated using:

- Heat pump only (steam production heat pump, [SPHP]).



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- A combination of heat pump and steam compression (SPHP+SC).

Notably, there is also mechanical vapour recompression (MVR), a well-established waste heat recovery method, which is primarily used in industrial processes, such as evaporation and distillation. However, the focus here is on heat pumps as a replacement for fossil generated steam.

The efficiency of the heat pump system is defined by the coefficient of performance (COP). The COP is calculated as the ratio of the rejected heat and compressor work, and depends on both temperature lift and cycle efficiency. In general, COP calculation is simple: it is the difference of thermal power at the sink output and the sink input over the compressor work:

$$\text{COP} = \frac{\Delta Q_{\text{sink}}}{W_c}$$

While steam compressors – with appropriate interstage cooling to optimise its compression efficiency – typically have a COP slightly below 1, a SPHP+SC typically yields a COP ranging from just under 2 to over 3, depending on the refrigerant used and the cycle configuration. The COP's calculation is defined as:

$$\text{COP} = \frac{\Delta Q_{\text{sink}}}{W_c(\text{SPHP}) + W_c(\text{SC})}$$

The  $\Delta Q_{\text{sink}}$  represents the difference in thermal power between the steam compressor discharge and the heat pump sink inlet (usually the feed water).

Figure 2 depicts a standard heat pump principle for steam production feeding into an industrial process steam header. The SPHP system consists of a typical closed-loop heat pump cycle designed to generate steam at a low-pressure level. It includes an evaporator situated at the heat source, followed by a compressor, a condenser located at the heat sink for heating and evaporating the feed water, and a throttle valve concluding the heat pump cycle.



**Figure 3.** Integrally geared compressor (source: MAN Energy Solutions).

Depending on the refrigerant and heat pump cycle configuration used, the heat pump cycle alone can produce steam at low-pressure levels (e.g., up to 2 bara).

A steam compressor (SC) is installed on the steam side of the heat pump to supply the process steam header. This compressor can be combined with the heat pump compressor or installed separately.

The pressure of the steam between the heat pump and the steam compressor is a variable to realise the best overall efficiency (COP) of the installation. Lower interim pressure enhances efficiency and necessitates a larger steam compression component size. Actively cooling the steam during compression using injection water boosts overall efficiency and reduces the heat pump size.

The types of compressors typically employed for industrial heat pumps encompass scroll, reciprocating, screw, and both inline and radially geared centrifugal compressors. However, in large-scale industrial applications exceeding 10 MWth, centrifugal compressors are utilised exclusively. Figure 3 illustrates a typical radially geared centrifugal compressor. They have a strong track record within the chemical and petrochemical industries and are designed according to widely recognised industrial standards.

In general, various refrigerants can be employed for large heat pump cycles. The thermodynamic properties of the refrigerant significantly influence the heat pump process and, consequently, the choice of the working fluid plays an essential role in process optimisation. Therefore, it is important to consider various categories of properties, including:

- Thermodynamic properties, such as critical temperature and pressure, and evaporation/condensation enthalpy.
- Chemical properties related to compatibility with component materials, such as metals, seals, and chemical stability.
- Environmental factors, such as potential for greenhouse warming, ozone depletion, and degradation products.
- Safety considerations, including aspects such as flammability, toxicity and detectability, among others.
- Commercial factors such as cost (CAPEX and OPEX), and supplier market availability.

Refrigerants are categorised as either natural or synthetic. Natural refrigerants primarily consist of hydrocarbons such as butane, propane, ammonia and CO<sub>2</sub>. Synthetic refrigerants like hydrofluorocarbons (HFCs) are specifically designed for particular applications. They have replaced chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), which contribute to ozone layer depletion. Due to the current uncertainty surrounding synthetic refrigerants, for instance, with F-Gas regulation and REACH (Regulation of per- and polyfluorinated substances PFAS), natural refrigerants are deemed more suitable for future use.

The performance of natural heat transfer fluids, as measured by COP, is comparable to the process efficiencies achievable with current synthetic heat transfer fluids across the application range. Overall COP values (including both heat pump and steam compression) indicate that ammonia, butane and propane are the most efficient natural refrigerants



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to utilise. Among them, ammonia generally exhibits the highest COP for steam production, making it the top performer with the highest power density.

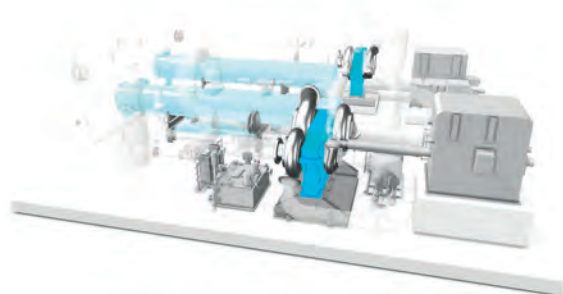
Future research focusing on heat pump refrigerants is imperative to explore potential advancements, such as tailored azeotropic mixtures, aimed at optimising fluid properties in process steam generation. An azeotropic mixture comprises two or more liquids with identical composition in the vapour phase and closely matching boiling points. An exploration of this topic could lead to an improvement in cycle efficiency.

## Efficiency redefined: generating process steam using heat pumps

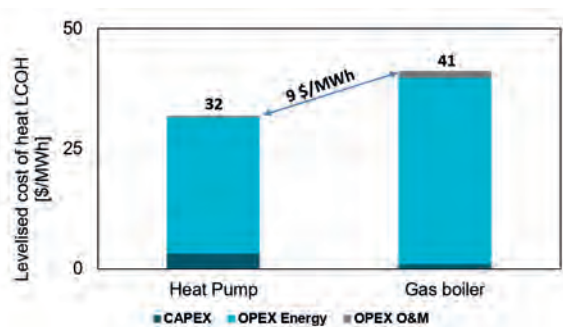
The term 'heat pump' is not new to the petrochemical industry. In the production of propylene, heat pump compressors have been utilised in the recovery and purification phase of the propane dehydrogenation (PDH) process (e.g. oleflex) for several years.

Depending on the process steam conditions at a common steam header, an optimised heat pump cycle can be installed for lower steam conditions (e.g., below 2 bara). In case the process requires higher steam conditions, an additional compressor stage can be integrated into the heat pump compressor or installed separately as a motor-driven compressor adjacent to the heat pump.

The planning of this system aligns well with a greenfield installation. For a brownfield installation, the entire system undergoes optimisation to accommodate the available space



**Figure 4.** Typical arrangement drawing of a heat pump with an additional separate steam compressor.



**Figure 5.** Levelised cost of heat (steam production), comparison between heat pump and gas fired boilers. Basis: estimated electricity price of US\$80/MWh and gas price of US\$35.31/MWh.

and ensure smooth integration into the existing process plant infrastructure.

Figure 4 illustrates a typical configuration of a heat pump system dedicated to process steam generation. This arrangement consists of a heat pump system equipped with a motor-driven compressor, evaporator, condenser and auxiliary components, as well as a separate motor-driven steam compressor.

## Economic comparison

Heat pumps face competition from conventional heat generation systems used in the petrochemical and chemical industries, typically powered by fossil fuels. This includes boilers and conventional combined heat and power systems (CHP). Despite the environmental advances, there remains a general scepticism about their economic viability, often stemming from a lack of comprehensive knowledge about the actual incurred costs. An economic analysis serves as a helpful tool to clarify this issue.


Therefore, it is necessary to compare the cost of heat produced by heat pumps with that of conventional methods, where fuel expenses and the cost of carbon emission certificates (e.g., in Europe) drive major cost considerations. This economic comparison is illustrated by following a brief example of a heat pump cycle with an integrated steam compressor against a natural gas fired boiler. The heat pump system generates 85 tph of superheated steam at conditions of 3.5 bar(a) and maximum temperature of 200°C. The heat source is a cooling water circuit in a petrochemical production process with a temperature of approximately 60°C. Ammonia is selected as the refrigerant in the heat pump circuit. With this configuration, a COP of 2.8 can be achieved.

The heat pump will run for 8500 hours annually with an estimated commercial lifespan of 30 years. Although the CAPEX for a heat pump system is approximately three times higher than that for a gas-fired boiler, the OPEX for the heat pump is comparatively lower than that of a boiler.

The payback period of the heat pump in this example is around 5.5 years. Additionally, the levelised cost comparison depicted in Figure 5 validates the utilisation of a heat pump for steam production as a viable business decision over a boiler.

## Summary

The chemical and petrochemical industry ranks among the biggest CO<sub>2</sub> emitters in the industrial sector. Industrial heat pumps are able to convert the waste heat from chemical processes and cooling water sources into useful process steam, reducing dependency on fossil fuels and thereby decarbonising this industrial sector.

Heat pump technology solutions, relying on well-proven industrial components, are reliable and significantly enhance overall production process efficiency and economics. 

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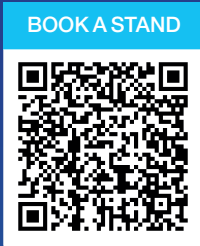




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# HIGH-PERFORMANCE butterfly VALVE SELECTION

**Karin Pharr, Emerson, USA,** considers how recent advances in valve and seat design allow high-performance butterfly valves to achieve excellent sealing over an extended service life.

**H**igh-performance butterfly valves are a staple in the chemical and petrochemical industries. Whether automated or manual, they can be found throughout process facilities, and they play a key role in equipment operation, isolation, and maintenance.

There are crucial design features and capabilities that can dramatically impact the performance and reliability of these valves. This article will discuss those features, and help users make the best design decision when evaluating alternatives for on/off valve applications.

## Butterfly valve applications

Butterfly valves are often the best choice for equipment isolation and other on/off applications.

They are generally less expensive than ball or plug valves, and they take up significantly less space when installed. High-performance butterfly valves also offer similar or better sealing capability as compared to ball or plug valves.

High-performance butterfly valves employ advanced offset seat designs and special sealing surfaces to allow them to achieve bubble tight, zero leakage, while taking up significantly less space in the pipe in which they are installed. Despite the revised body and seat designs, these valves still cost less than ball or plug valves. This makes them an ideal and cost-effective solution for most on/off process applications requiring zero leakage shutoff.

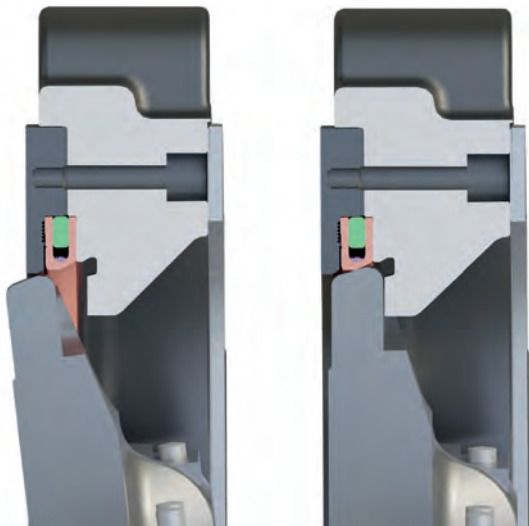
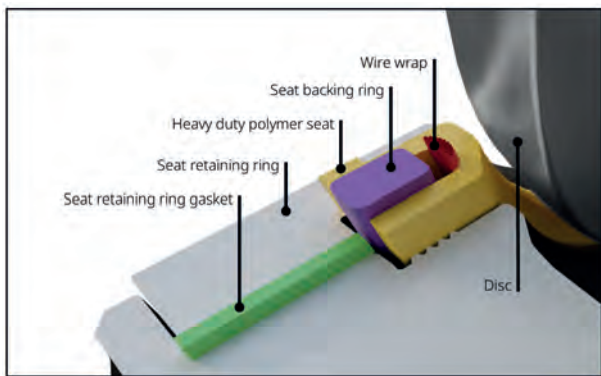
Many high-performance butterfly valve designs are available, but they are not all equal. Certain design improvements allow some valves to last longer, while consistently providing very tight shut off, with significantly lower life cycle cost. This article will identify and discuss these and other design features that should be considered during the valve selection process.

## Seat design

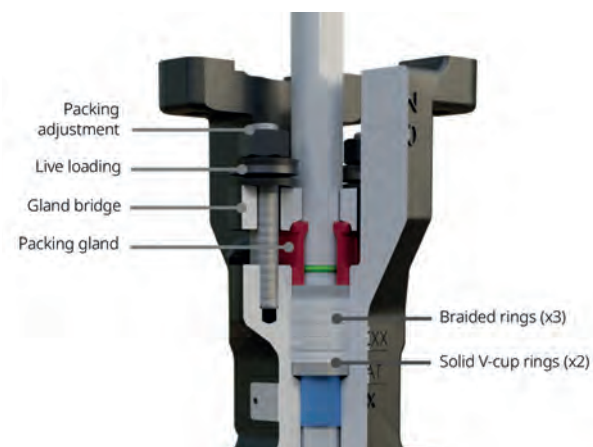
Selection of a proper high-performance butterfly starts with a careful evaluation of the valve disc and seat. Obviously, the ability of a valve to shut off tightly over a long life is a key performance requirement, and the valve and seat design ultimately determine how well a particular valve will perform in this regard.

The valve disc can be made of a variety of materials, but it should always include some means of additional hardening in the sealing areas to minimise wear, and better designs will incorporate a double-offset





**Figure 1.** Long life high-performance valves employ a heavy-duty polymer seat that uses backing rings, internal wire wraps, and carefully formed gaps so the seat can adjust to the valve disc as it cams into the seat. This combination provides a bubble-tight seal over an extended service life.



**Figure 2.** Very low emission packing is a crucial requirement of any high-performance valve in chemical or hydrocarbon applications. Near zero fugitive emissions over an extended service life are possible through application of a variety of specialty materials and careful engineering.

alignment to ensure a tight seal. This disc design must be paired with a carefully designed seat that can mold and adjust to the valve disc, while providing a long service life.

Very tight shutoff and long-term reliability are often mutually exclusive in many valves, since the tighter a disc cams into the seat, the faster the seat tends to wear and degrade. Fortunately, recent designs allow some valves to maintain bubble tight leakage rates over a greatly extended service life (Figure 1).

To provide these benefits, an advanced seat design and a disc modification that minimises contact are required. The seat itself is made of PTFE or RTFE, and it is supported with a backing ring and strengthened by wire wrap internal to the seat itself. This combination creates a very strong seat which can move and adjust to the valve disc as it meets the seat, providing bubble tight shutoff, while wearing very slowly.

The adjustable seat provides an interference fit with the valve disc, allowing the valve to achieve bubble tight closure from full vacuum to rated pressure conditions. It also maintains these leakage rates with pressure on either side of the valve, allowing it to perform equally well, regardless of how it is installed in the line with respect to the direction of process media flow.

A second innovation involves modification of the disc and shaft such that the disc completely disengages from the seat within seven degrees of travel. This reduces wear on the valve and further improves the life of the seat since disc/seat contact is minimised.

## Stem seal design

Another area worth evaluating involves the design details of the stem packing and sealing. Today's environmental laws are becoming increasingly stringent regarding fugitive emissions, so very low leak rates in the valve packing are required. Unfortunately, valve packing designs must satisfy contradictory requirements. Leakage rates must be maintained near zero even as the packing wears, which typically requires high compression of the packing. However, the packing must provide a low friction surface that allows smooth valve stem rotation throughout the life of the valve.

Modern environmental seal packing addresses this issue through a combination of specialty materials and advanced packing designs (Figure 2). Live loaded packing washers maintain constant pressure on the packing rings, which consist of a number of braided and v-cup rings fashioned from different materials to meet the pressure and temperature requirements of the application. To lengthen the packing life and avoid friction, the stem must be made from a high-hardness material.

When designed correctly, this type of packing can achieve and maintain near zero leakage performance for years of service. Easily accessible packing adjustment nuts allow the valve packing life to be extended still further.

## Valve design

Beyond the valve seat and packing, which allows certification according to ISO 15848-1 BH CO3, there are a number of additional body design features that should be considered when selecting a valve (Figure 3). Key components include:

- Standard face-to-face valve dimensions per EN 558 Series 20 and Series 25.
- An elongated area between the packing adjustment area and the valve body to allow the pipe and valve to be



insulated, while still allowing packing maintenance if required.

- An integrally cast ISO 5211 mounting pad that allows most actuators to be mounted directly to the valve, avoiding the need for additional brackets or couplings.
- A strong shaft securely attached to the disc, while minimising the surface area so that the valve flow capacity remains as high as possible.
- Incorporation of a blow-out proof shaft protection per EN 12569.
- A lug body is capable of dead-end service.

These features ensure the valve will provide high capacity, reliable performance across a wide range of applications. Bidirectional sealing that operates independent of system pressure allows the valve to be installed in the pipe, regardless of orientation.

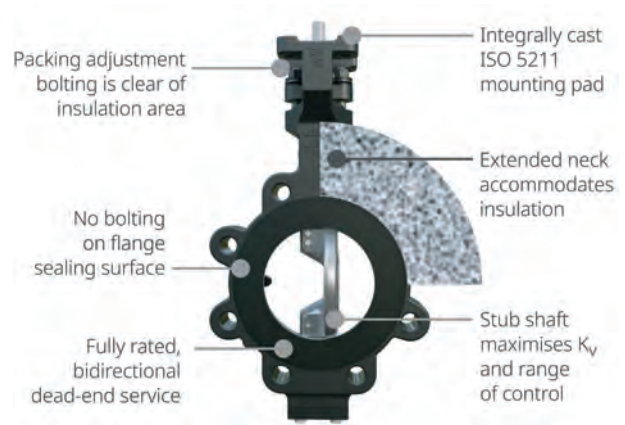
### Maintenance friendly

Over time, seat and packing wear are inevitable, so every high-performance butterfly valve should allow easy replacement of the packing and seat components (Figure 4).

An easily maintainable valve contains seating and packing components that can be serviced or replaced without disassembly of the valve disc and stem.

### Designed to key standards

Any high-performance valve should be designed to meet a variety of applicable standards and certifications including:



**Figure 3.** High-performance valves (Emerson's Keystone K-LOK® Series 38, shown) incorporate design features to accept a wide range of actuators, maximise valve capacity, and provide bubble tight sealing in bidirectional and dead-end service applications.

- Directive 2014/68/EU of the European Parliament and of the Council: establishes safety criteria for pressure equipment products used in Europe (PED).
- NAMUR NE 167: a technical recommendation issued in 2021 that incorporates the latest best practices for pressure-bearing and wetted parts of valves, final control elements, and field devices.

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**Figure 4.** High-performance valves (Keystone K-LOK Series 38, shown) simplify maintenance and replacement of valve seat and packing seal components with easy-access design that reduces maintenance time and complexity.

- EN 593: establishes minimum design requirements for metallic butterfly valves in isolating, regulating, and control applications.
- EN 12569: provides a range of design requirements for valves installed in chemical and petrochemical applications.
- ISO 15848-1 Tightness Class BH and Endurance Class C03: ensures the valve achieves and maintains very low fugitive emissions across many cycles.
- EN 12266-1 Leakage Rate A: provides test procedures to confirm the valve provides zero leakage/bubble tight shutoff.

## Conclusion

High-performance butterfly valves offer an economic solution for on/off applications in the chemical and petrochemical industries, and within a smaller footprint than other valve designs. Improvements in valve seals, stem packing, and body design enable modern high-performance butterfly valves to achieve and maintain bubble tight shutoff and near zero fugitive emissions over a very extended valve life.

When evaluating options for a valve project, it is important to consult with a valve vendor and carefully examine the design features and options of the various alternatives. Very low-cost options may be available, but better valve designs will provide superior performance over a much longer service life, justifying the initial price differential. [13](#)

## Note

All Figures courtesy of Emerson.

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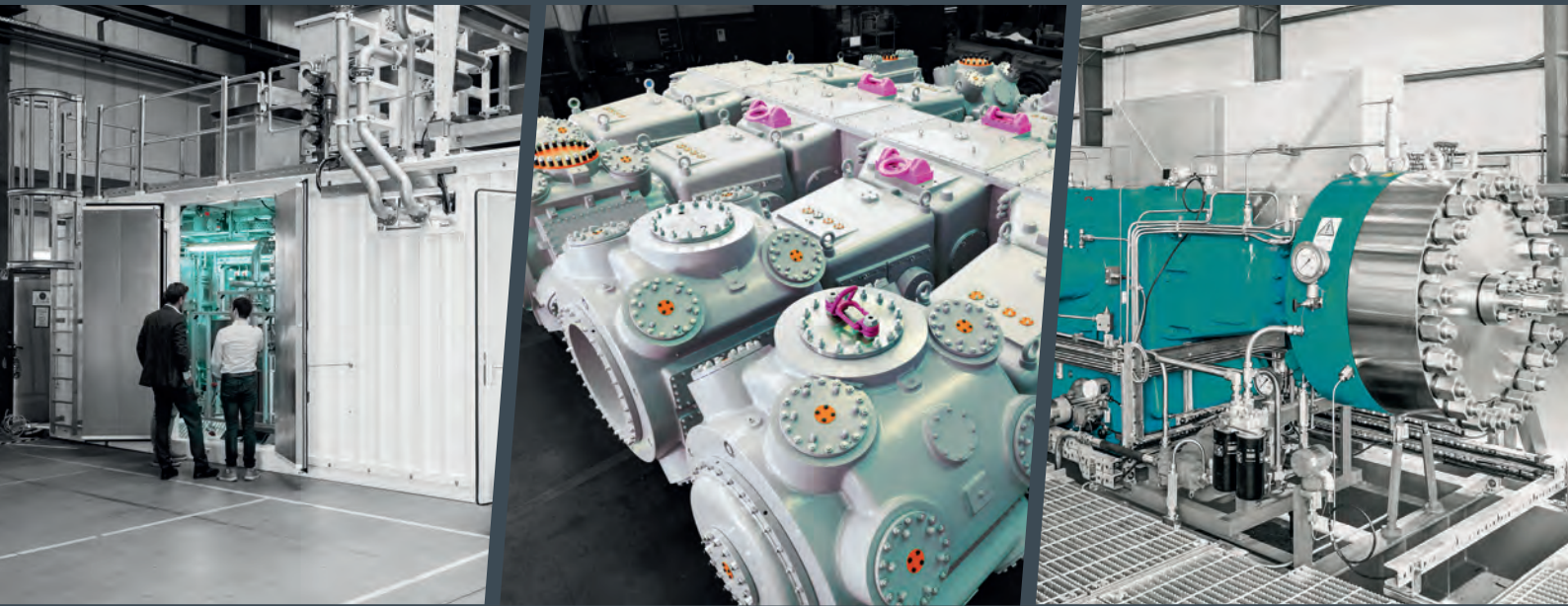


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