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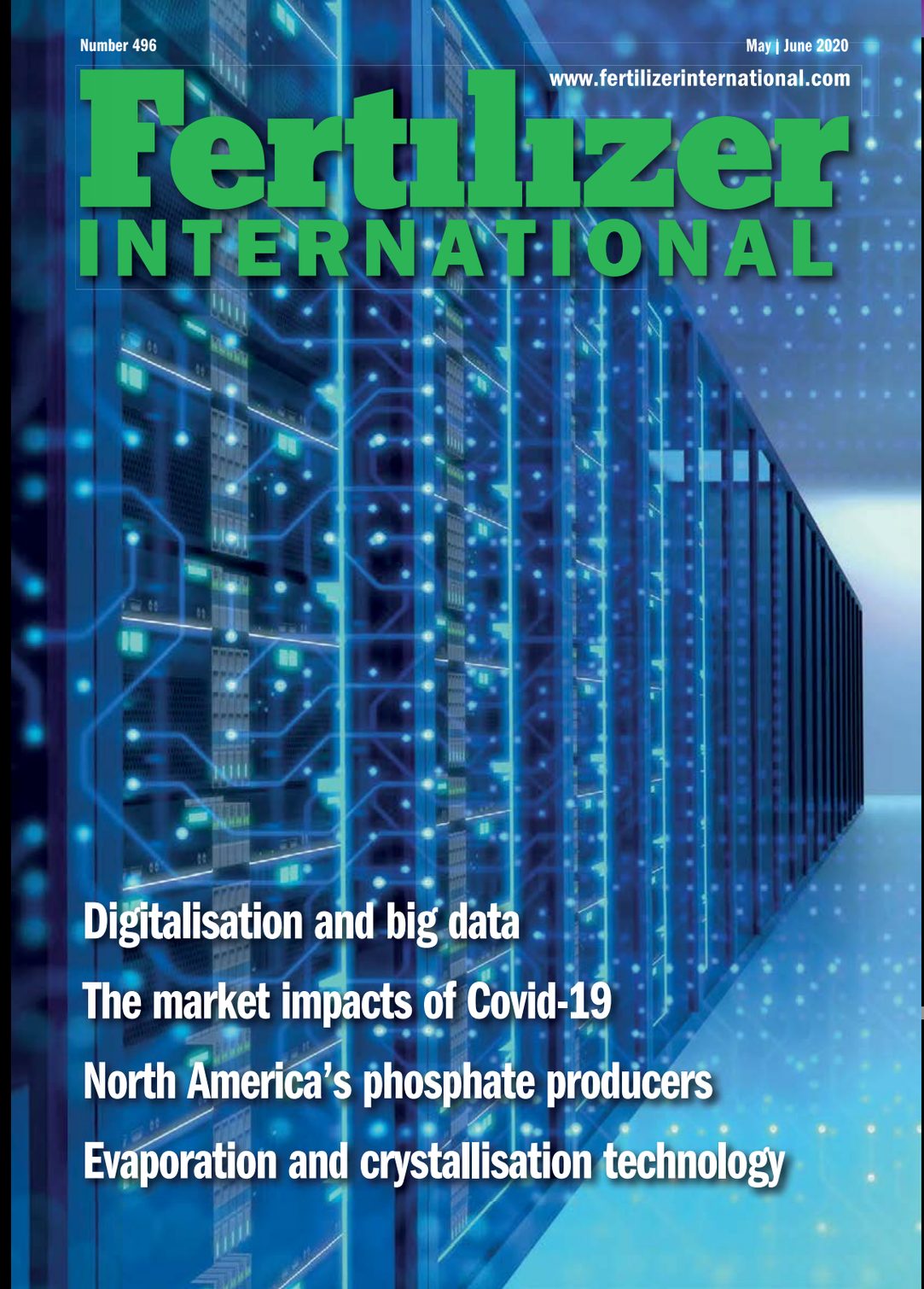

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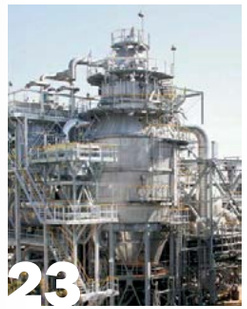

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Lockdown lessons

The arrival of the Covid-19 pandemic has abruptly ended lives and livelihoods during its pernicious and inexorable spread across the globe. The fertilizer industry has not been immune to its parlous effects.

Covid-19's damaging impacts could be felt for years too.

Certainly, the short-term outlook for global fertilizer demand does not make for pretty reading, as commodity analysts Argus commented recently. Citing the latest forecast from the International Fertilizer Association (IFA), they reported in May that:

"A combination of poor farm economics and logistical disruptions resulting from the Covid-19 pandemic and related lockdowns will see global fertilizer demand fall by nearly three percent in the year July 2020-June 2021 to 184 million tonnes."

The medium-term outlook is equally downbeat. Rising risks to food demand from an economic slump caused by Covid-19 could see fertilizer demand growth slow to less than one percent per annum out to 2024.

These depressing downsides may not be fully realised. Uncertainties abound – that is the one harsh lesson Covid-19 has taught us to date. The principal uncertainties being the duration of the health crisis and the effectiveness of government containment and mitigation measures.

The question on everyone's lips is when will life get back to normal? The honest truth is that no one knows – or what the 'new normal' will look like when it arrives.

So what *have* we discovered about Covid-19's effects so far? Well, the capacity of the coronavirus crisis to inflict damage on agriculture and the fertilizer industry seems to depend on two things – timing and what IFA calls "a patchwork of geographical factors".

The timing of the pandemic's onset has proved most favourable to agriculture in the global north. Here, the effect on fertilizer deliveries has been relatively slight in regions such as North America and Europe – as most fertilizers had already been purchased and delivered for the main growing season. Equally, in the southern hemisphere, with March-April marking the end of the growing season, there has been no strong, immediate demand for large volumes of fertilizers anyway.

Instead, the pandemic's arrival was particularly badly timed for Asian and African countries where the crop season occurs later in the year. With fertilizer sales still pending, or deliveries still in transit, the risk of delay or disruption to fertilizer supply in these regions has been much greater. To date, it has been farmers in China and India, where large volumes of fertilizers were in the pipeline when the pandemic hit, that have been left most vulnerable to delays and non-delivery.

Not all regions are equal either – as IFA points out – due to accidents of geography. Some, like the EU and Latin America, for example, are highly dependent on fertilizer imports, while other countries and regions, notably India and Africa, are particularly dependent on agricultural labour.

A country's crop mix – another geographic factor – is also critical when it comes to the economic effects of Covid-19.

The good news is that we know demand for wheat and rice – which together account for almost 30 percent of fertilizer consumption – has remained resilient during past economic downturns. The consumption of more expensive fruit and vegetables, in contrast, is more sensitive to falls in household incomes. Intensive cultivation and their perishable nature also make fruit and vegetables susceptible to both labour shortages and logistic delays.

Highly-traded feed crops such as maize and soybeans are doubly vulnerable, being exposed to both supply disruption and falls in meat consumption. Biofuel crops – maize in North America, sugarcane in Brazil and palm oil from Indonesia/Malaysia – have also been left exposed to the collapse in price and demand for oil that has accompanied the global spread of Covid-19.

Governments have not stood idly by, however. Support is on its way with 23 countries so far having officially declared fertilizers as essential. The United States, for example, has channelled $15.5 billion in support towards agriculture, while the EU has extended state aid for its farms. In India, the government has stepped-in to procure pulses and oilseeds.

In response to unprecedented market conditions, a large part of our news section this issue is dedicated to Covid-19 updates (page 12). Also in this issue, CRU have shared their authoritative and in-depth analysis of Covid-19's impacts (page 18).

As always, *Fertilizer International* will continue to report on and support the industry during the current pandemic, as it has done for more than 50 years now. That much *is* certain.

"Rising risks to food demand from an economic slump caused by Covid-19 could see fertilizer demand growth slow all the way out to 2024.

Simon Inglethorpe, Editor

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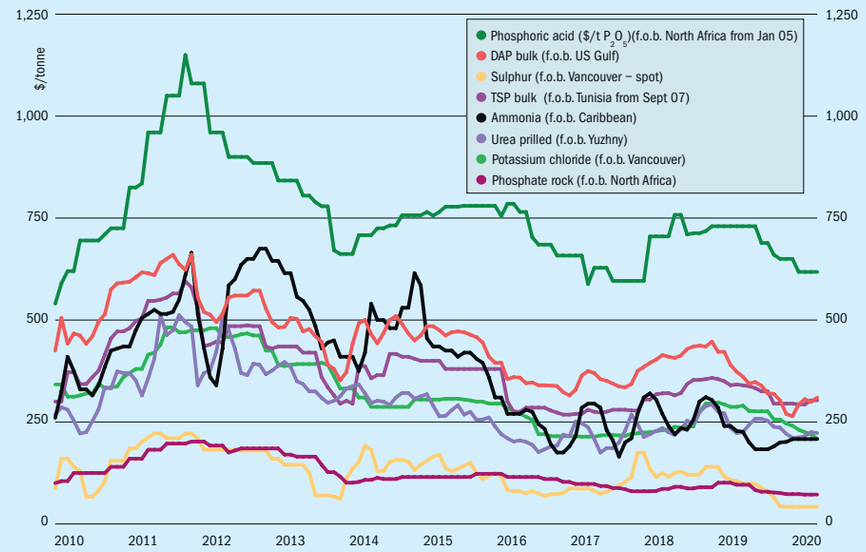
Market Insight

Historical price trends $/tonne



Source: BCInsight

Market Insight courtesy of Argus Media

PRICE TRENDS

Urea: Prices peaked in early March at $260-265/t f.o.b. (Egypt and Middle East) and have declined since, falling by about $30/t by the end of April. Despite strong demand for urea for April shipment, particularly from India, Australia, Europe and the US, this was outweighed by uncertainty created by the Covid-19 pandemic. Nitrogen fertilizer prices have, however, held up better than other energy-related commodities, partly because the pandemic coincided with the peak demand period in the northern hemisphere.

India bought nearly 750,000 tonnes of urea for April shipment. Timely rain also prompted Australia to purchase 5-6 spot cargoes of granular urea from the Middle East, Southeast Asia and China. In the US, meanwhile, prices have remained at a premium to other markets in April, pulling in more volumes. Globally, the market is waiting for demand to emerge from other countries for May. It is also focussed on likely export prices and volumes from China, especially as lower gas and coal prices mean Chinese suppliers are more competitive than last year.

Phosphates: The market was increasingly affected by the global Covid-19 pandemic in March and April, as enforced lockdowns hit production capacity, especially in Jordan and India. Several Indian phosphates producers shut their plants in March, and import demand from Indian buyers has picked up significantly as a consequence. Imports lined-up by India for the second-quarter include 1.19 million tonnes of DAP, although this still lags the 1.95 million tonnes scheduled for the same quarter last year.

Chinese producers re-emerged in April, after several months affected by coronavirus lockdowns and strong domestic demand, with production capacity becoming available for export, following the end of the Chinese domestic season. Indian DAP prices varied from $308/t cfr in early March to $315/t cfr at the end of April. Chinese DAP prices remained almost stable at $303-$306/t f.o.b. over this period.

West of Suez, demand in Brazil and Argentina was muted after significant purchases earlier in 2020. Brazilian MAP prices softened from $328/t cfr in early March to $308/t cfr in late April. US barge prices (Nola DAP) firmed from $278/st f.o.b. at the beginning of March to $280/st f.o.b. at the end of April.

Potash: Prices continued to fall in March and April. The weakening economic outlook, the spread of Covid-19 and a lacklustre import schedule for January and February all took their toll on demand.

Potash suppliers made some production cuts last year in response to oversupply. But demand has dropped further since then. Import/export data for Jan-Feb show MOP imports have dipped by 27 percent year-on-year, allowing stocks to draw down as seasonal demand ramps-up. This is true of Brazil, the US, Europe and Southeast Asia, all of which are still oversupplied, albeit much less so in recent weeks.

Market price summary $/tonne – End April 2020

Nitrogen	Ammonia	Urea	Ammonium Sulphate	Phosphates	DAP	TSP	Phos Acid
f.o.b. Caribbean	200-215	-	f.o.b. E. Europe	f.o.b. US Gulf	297-323	-	-
f.o.b. Yuzhny	210-215	215-225	110-126	f.o.b. N. Africa	294-316	275-320	560-675
f.o.b. Middle East	200-220	226-245**	-	cfr India	314-320	-	590*
Potash	KCl Standard	K_2SO_4	**Sulphuric Acid**			**Sulphur**	
f.o.b. Vancouver	182-236	-	cfr US Gulf	35-55	f.o.b. Vancouver	38-45	-
f.o.b. Middle East	179-239	-	-	-	f.o.b. Arab Gulf	37-50	-
f.o.b. Western Europe	-	423-490	-	-	cfr N. Africa	55-70	-
f.o.b. Baltic	180-235	-	-	-	cfr India	55-75+	-

Prices are on a bulk, spot basis, unless otherwise stated. (= contract ** = granular). Phosphoric acid is in terms of $/t P_2O_5 for merchant-grade (54% P_2O_5) product. Sulphur prices are for dry material. (+ Quotes for product ex-Arab Gulf). n.a. = not available.*

Sulphur: Following a flat January and February, prices across the globe started to increase at the beginning of March, as buyers looked towards April loading cargoes. China also stepped back into the market for cargoes, needing to play catch-up after its lockdown and responding to spring application season demand. Prices eventually reached five-month highs due to a combination of: three months of tight supply east of Suez, buyers looking to cover second-quarter demand, and China's return. Pockets of supply-side tightness west of Suez, due to refiners lowering their run rates in response to coronavirus measures, also contributed. Market sentiment did eventually turn bearish, however, as lockdown measures took hold globally, causing prices to soften in late March.

MARKET OUTLOOK

Urea: Continuing price falls look likely given the falling demand from the industrial sector, a consequence of reduced economic activity and lower feedstock costs. Natural gas and LNG prices are very low, while corn prices have suffered due to the reduced demand for ethanol. CME futures for new crop corn, for example, fell from $3.70/bushel in early March to $3.10/bushel currently. The scene is set for urea prices to remain under pressure in May and June.

Phosphates: Further demand from India and Pakistan is expected in coming months. Chinese suppliers are looking for an outlet now that their domestic season has come to an end – but will be facing Indian market competition from Moroccan, Saudi Arabian and Russian suppliers. East Africa and Latin America could still provide outlets for Chinese product. Buyers in Latin America are, however, in no hurry to purchase ahead of the *safra* application season in the third-quarter.

Potash: The market could be at a turning point with prices levelling-off soon. Producers will still need to react quickly to further falls in demand, though, against the backdrop of economic recession and myriad other Covid-19 impacts. These are collectively adding a significant downside to the price outlook. But if national governments' prioritise food security during the pandemic, as is the case in Europe currently, then demand could remain relatively unaffected.

Sulphur: Tight supply is set to continue in those regions where sulphur production is reliant on oil refining as – with large swathes of the world still under lockdown – the demand for mainstay oil products such as jet fuel and petrol remains low. Prices are nevertheless still expected to soften globally, despite the drop in sulphur supply across many markets west of Suez, as large end-user consumers in metals, mining and chemicals markets have reduced operational rates dramatically, if not having already closed completely. ■

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BELARUS

BPC agrees potash contract with China

A consortium of Chinese buyers has agreed the first potash contract with the Belarusian Potash Company (BPC) since September 2018.

The deal is significant as BPC, the trading arm of state-owned mining company Belaruskali, controls more than 20 percent of the global potash market. The Chinese buying c onsortium includes the China National Agricultural Means of Production Group and state-owned Sinofert and CNOOC.

Controversially, the new potash contract was agreed on the 1st May at a price of $220/t cfr, sharply down by some $70/t from previously agreed levels. BPC cited the difficult macroeconomic backdrop to its negotiations – including sharp local currency devaluations, an almost unprecedented oil price collapse, other commodity price falls and the Covid-19 pandemic.

"The price of the new China contract builds a firm foundation for the stabilization, recovery and further incremental development of the global potash market," BPC said in a statement.

Although the total contract volume has not been disclosed, BPC says it will supply volumes to China for the rest of this year. Annual potash contracts in China usually see 5-6 million tonnes agreed between international suppliers and domestic buyers, according to Argus Media.

"Although this underlines the magnitude of spot price erosion since 2018, it nevertheless sets a new floor for the market," Humphrey Knight, CRU's senior potash analyst, told mining.com. "Suppliers will now hope this finally brings stability to weak spot prices and ultimately tightens global product availability."

Potash stock levels are at a record high and exporters will wish to clear these as soon as possible, Knight said. This means it will be months before China requires significant new potash supply, in his view.

Rival Russian potash producer Uralkali reacted strongly to news of the BPC contract and the settlement price.

In a statement, Uralkali said it would "consider whether it is prepared to conclude contracts at the price set by BPC". Uralkali said the terms agreed by BPC "do not reflect the real market situation that is developing at this time, or its outlook". It went on to describe the agreed price as inappropriate for both the contract and the potash industry as a whole.

"Potash producers incur high investment costs in order to maintain existing production capacities and develop new deposits. This activity is necessary to meet the growing global demand for fertilizers. If contracts are agreed at the price levels agreed by BPC, in the long term this will drive producers to cut their capital investment and, ultimately, will lead to a shortage of potassium chloride in the market," Uralkali said.

China imported around one million tonnes of potash from Canada, 690,000 tonnes from Russia and 290,000 tonnes from Belarus during the first-quarter of 2020.

RUSSIA

Aumund secures large PhosAgro order

PhosAgro has ordered eight chain bucket elevators from Germany's Aumund Group. These are required for the company's Metachem production plant near St Petersburg, Russia.

The eight high-capacity bucket elevators will be installed at the Metachem plant for handling monoammonium phosphate (MAP) and diammonium phosphate (DAP) produced on-site. The MAP and DAP handling capacities of the bucket elevators range from 100-400 t/h. They vary in height from 18 metres to 43 metres. Five of the bucket elevators have already been dispatched, with the three others due to follow shortly.

Aumund made its initial sale to PhosAgro's Metachem plant back in 2014, its very first Russian fertilizer industry equipment order. The company has also supplied equipment to PhosAgro's Cherepovets and Balakovo plants in recent years. Aumund Group's relationship with PhosAgro also extends to its subsidiary Schade – which has supplied portal reclaimers to the Cherepovets plant previously.

PHOTO: PHOSAGRO

Aumund has also supplied PhosAgro's Cherepovets fertilizer production complex.

BELGIUM

Prayon part-buys EcoPhos assets

Prayon has acquired the intellectual property of phosphate technology company EcoPhos.

The purchase, which includes the company's patents portfolio and process know-how, comes after EcoPhos filed for bankruptcy in March. Prayon has also bought Technophos, an EcoPhos-owned industrial demonstration plant in Varna, Bulgaria, as part of the deal.

EcoPhos, a Belgian company based in Louvain-la-Neuve, was founded by its CEO Mohamed Takhim in 1996. Innovative modular process technology developed by the company is capable of producing high-quality phosphoric acid from low-grade phosphate rock. This proprietary chemical production route does not involve beneficiation, has low energy requirements and generates pure gypsum as a by-product. The phosphoric acid produced is suitable for the manufacture of fertilizers and feed, food and technical phosphates.

EcoPhos owned 10 international patents, employed more than 300 people and generated revenues of €170 million, as of 2017. Its wholly-owned subsidiary Aliphos is Europe's largest feed phosphates producer, owning three manufacturing plants with a combined production capacity of 620,000 t/a. EcoPhos was also developing joint venture projects in Egypt and India with Evergrow and GNFC.

Aliphos purchased a major feed phosphates plant in Rotterdam in the Netherland from Tessenderlo in 2009. A second feed phosphates plant in Devnya, Bulgaria, was originally developed in 2002 as Decaphos, a joint venture between EcoPhos and Agropolychim. The latest Aliphos plant, a 220,000 t/a capacity operation located in Dunkirk, France, opened in 2017 and uses EcoPhos technology.

"Prayon is very happy to announce this acquisition since it fits perfectly with our strategy," said Marc Collin, Prayon's chief technology officer. "The process portfolio proposed by EcoPhos is complementary to that offered by Prayon through its licensing division. We will continue to promote them in parallel as they have their own particular specificities. It is also an important step towards our goal to become an important actor of the circular economy."

Belgium-headquartered Prayon is jointly owned by the Wallonia regional investment company (SRIW) and Morocco's OCP Group. The company employs over 1,100 staff and manufactures purified phosphoric acid and a wide range of phosphate products for the fertilizer, food and industrial markets. It operates four production sites internationally – two in Belgium, one in France and another in the United States. Its Prayon Technologies (PRT) arm provides the know-how and technology for more than 60 percent of the world's phosphoric acid manufacturing plants.

TURKEY

Tecnimont wins fertilizer plant contract

Maire Tecnimont has signed a €200 million construction contract to build a new fertilizer plant for Gemlik Gübre Sanayii Anonim Sirketi.

The engineering, procurement and construction (EPC) contract is for a new urea and urea ammonium nitrate (UAN) plant at Gemlik, 125 kilometres south of Istanbul. The plant will have a production capacity of 1,640 t/d for granular urea and 500 t/d for liquid UAN.

The project to build the Gemlik plant should be completed within three years. The EPC contract covers the plant's engineering, the supply of all equipment and materials, and construction and erection works. The plant will use urea technology licensed by Stamicarbon, the Netherlands-based, wholly-owned subsidiary of Maire Tecnimont.

Gemlik Gübre is part of Yildirim Holding, a multi-billion dollar diversified conglomerate. The Turkish industrial company has interests ranging from chemicals and fertilizers to ports and logistics, and metals and mining. It already produces ammonia and other fertilizers at the Gemlik site, which has direct sea port access to the Mediterranean.

Pierroberto Folgiero, Maire Tecnimont's CEO, said: "We are extremely proud of this new achievement that confirms [our] leadership in the fertilizer sector and allows us to expand our geographical footprint in a strategic market such as Turkey."

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TRINIDAD

Nutrien closes ammonia plant for three months

Nutrien has temporarily shut down one of the four ammonia plants at its Trinidad production site.

"We expect the shutdown to last for a minimum of three months," Nutrien said in a statement on 5th May, calling this a "difficult decision". The company said it will continue to monitor market conditions to assess if any further production changes are necessary.

The closed plant has the capacity to produce 600,000 tonnes of ammonia annually. Nutrien confirmed that its three other ammonia plants and one urea plant in Trinidad would continue to operate as normal.

AUSTRALIA

Incitec Pivot abandons fertilizer sell-off

Incitec Pivot Limited (IPL) has decided to retain its fertilizer business following the conclusion of a strategic review.

Incitec Pivot announced the possible sale of its fertilizer production arm in September 2019 as part of strategic review of operations. The three options on the table were sale, demerger, or retain and invest.

However, after exploring the level of market interest, discussions with potential buyers have now ended, IPL confirmed on 21st April. Canadian fertilizer giant Nutrien – which owns a major farm retail business in Australia – reportedly pulled out of talks in February due to the emerging coronavirus threat.

A careful assessment of a potential demerger was also undertaken by IPL. But the company has now concluded that – given the extraordinary market uncertainty and travel restrictions caused by the Covid-19 pandemic – retaining Incitec Pivot Fertilisers was the right decision for IPL and its shareholders. Its fertilizer production business will now "focus on [being] an industry leader in the supply of fertilisers and services to Australian agriculture", IPL said in a statement.

"The impact of the Covid-19 pandemic on market conditions has created extraordinary uncertainty," said Jeanne Johns, IPL's managing director and CEO. "The IPL Board has concluded that it is in our shareholders' best interests that we continue to… run the industry leading businesses of Incitec Pivot Fertilisers and Dyno Nobel to deliver quality products and services for our customers in the agricultural and resources sectors."

IPL reported that Covid-19 has not significantly affected its operations to date.

"During this period of disruption, we have worked closely with our customers, farmers, and federal and state governments to ensure the fertiliser supply chain remains robust, to provide essential nutrients for farmers to provide food for Australians," commented Ms Johns. "Recent widespread rainfall across eastern Australia has created significant demand by farmers for fertiliser. The business is also well-placed to benefit from any future improvement in global fertiliser prices."

INDIA

CIL restarts Visakhapatnam fertilizer plant

Indian fertilizer importer and manufacturer Coromandel International Limited (CIL) has partly restarted fertilizer production at its Visakhapatnam plant, according to a stock exchange filing. Its Kakinada production plant is also said to be still running.

The 25th April announcement follows cuts in output at CIL's production sites at the end of March, made in response to government-imposed Covid-19 lockdown measures.

CIL is one of India's largest domestic phosphate fertilizer producers, with a total annual capacity of 3.5 million t/a for DAP, SSP and NPKs. It operates major four major phosphate plants. Two of these are located in Andhra Pradhesh, at Kakinada and Visakhapatnam, together with two more plants at Ennore and Ranipet in Tamil Nadu.

The company produced 2.9 million tonnes of phosphate based fertilizers in 2018/19, according to Argus Media, together with an additional 561,000 tonnes of SSP from eight production locations.

CIL began to reduce operational staff numbers on 23rd March, immediately prior to the Indian government's initial 15-day coronavirus lockdown. CIL followed this by suspending operations at Ennore and Visakhapatnam on 26th March. The Indian government's lockdown measures were subsequently extended until 3rd May.

CIL's shutdown was just one of many Indian fertilizer manufacturing closures announced at the end of March. Rival producers IFFCO, Deepak, PPL, Fact, GSFC, RCF, Smartchem and Greenstar also announced plant closures and/or reductions in operating rates.

CIL's resumption of production follows a pronounced uptick in fertilizer raw material purchases, reports Argus Media. The company is still receiving contracted ammonia shipments, for example, with 5,000 tonnes scheduled for early-May delivery.

CIL also imports phosphoric acid for production, receiving 983,000 tonnes of phosphoric acid last year, according to Argus, with around 454,000 tonnes of this volume being OCP-supplied.

OCP has reported, however, that April-loading of phosphoric acid shipments to India had largely ceased, following the drop in phosphates production on the subcontinent, with the company granulating more DAP for the Indian market instead. CIL bought 50,000 tonnes of Moroccan DAP for May arrival, for example, to offset its lower domestic output.

NFL maintains fertilizer supply during lockdown

Major public sector producer National Fertilizers Limited (NFL) has confirmed that its urea plants remain fully operational and producing at more than 11,000 t/d.

These include NFL's Nangal, Bathinda and Panipat plants, together with its two plants at Vijaipur. The company says it has been working to ensure an adequate supply of fertilizers to farmers during the country's extended lockdown.

This news follows the Indian government's announcement that key industries such as agriculture, fertilizers and the movement of goods will be allowed to resume fully from 20th April, one aim being to allow harvesting operations by lifting restrictions on farming, plantations and fertilizer production units. As a result of India's lockdown measures, labour and logistical shortages over the last two months have severely delayed crucial *rabi* season harvesting, which normally ends in March. The *kharif* sowing period, which generally begins in April, has also been affected.

The commissioning of the new Ramagundam Fertilizers and Chemicals Ltd (RFCL) plant has also been interrupted by the Covid-19 outbreak. The commissioning of the new 3,850 t/d ammonia-urea complex was due to begin in April. But employees have now been furloughed until the end of India's lockdown.

RFCL is a multi-partner joint venture between NFL, Engineers India limited, the Fertilizer Corporation of India, the Telangana government, GAIL India Limited and the HTAS consortium. Prime Minister Narendra Modi marked the start of construction by laying a foundation stone for the revived plant in August 2016.

SWITZERLAND

EuroChem issues Covid-19 update

EuroChem says it has implemented a range of measures to reduce the adverse effects of the Covid-19 pandemic on its staff and the business.

In a 4th May statement, the Zug-headquartered fertilizer producer confirmed it had taken preventative risk management measures across all functions, including production, logistics, supply chain, markets, staff, IT and finance.

"All EuroChem plants continue to operate as normal and customers have experienced no significant disruptions with product deliveries. All relevant sanitation, social distancing and personal hygiene measures are in place and functioning efficiently at all locations," the statement said.

More than 6,000 EuroChem office staff worldwide are currently working remotely.

Announcing its results for the first-quarter of 2020, EuroChem revealed it had sold 6.4 million tonnes of fertilizers, mining and other products during this period, a 10 percent year-on-year increase.

"This strong set of results is built upon the determination, hard work and coordination of everyone across the company to ensure our products reach our customers, and farmers can grow the food the world needs," said Petter Ostbo, EuroChem's CEO. "In this challenging environment, our priority has been the health, safety and wellbeing of our colleagues and their families, and our business partners, while at the same time maintaining business continuity."

EuroChem says it is pressing ahead with the development of its two potash projects in Russia. The company's Usolskiy plant in the Perm Region produced 506,000 tonnes of MOP (muriate of potash, KCl,) during the first three months of this year. Progress continues apace at its sister VolgaKaliy potash project in Russia's Volgograd Region too, with drilling having now reached the mine's potash layer.

DUBAI

GPCA calls for uninterrupted supply of raw materials

The Gulf Petrochemicals and Chemicals Association (GPCA) wants to see the removal of restrictions affecting the supply of raw materials used to manufacture essential medical and hygiene equipment, saying these are absolutely crucial to fighting the Covid-19 pandemic.

The GPCA specifically called for the removal of high tariffs and other trade barriers currently in place in a statement on 1st April. The association is the official voice of the chemical industry in the Arabian Gulf, including fertilizer producers.

Its plea came after a pledge by world leaders during the G20's 'virtual' summit in March "to ensure the flow of vital medical supplies, critical agricultural products" and "resolve disruptions to the global supply chains".

The GPCA wants to see national governments and international legislators work more closely together to ensure the uninterrupted supply of essential chemical and petrochemical raw materials. In particular, it wants regulators to speed up the full implementation of the WTO's trade facilitation agreement (TFA). This is designed to simplify, modernise and harmonise import-export procedures and processes.

"Businesses are continuing to manufacture, in difficult circumstances, the various tools, safety equipment and personal protective equipment such as sterile gloves, masks, hand sanitizers and protective clothing urgently needed to protect the health and safety of people and medical personnel, " said Dr Abdulwahab Al-Sadoun, the GPCA's secretary general. "In the current crisis, the role of the chemical industry in ensuring the steady and reliable supply of vital raw materials and products has never been more pronounced."

GPCA has particular concerns over current Indian anti-dumping measures on imports from Saudi Arabia, Kuwait, Oman, UAE and Singapore. These are jeopardising $543 million of mono ethylene glycol (MEG) exports from the Gulf region into India, in its view. ■

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People

Ben Pratt joined Mosaic's senior leadership team at the start of April, having been appointed senior vice president (SVP) for government and public affairs. He was previously the company's vice president for corporate public affairs, with responsibility for corporate communications, social responsibility and US federal government relations.

"Ben has brought tremendous value to Mosaic over the past eight years," said Joc O'Rourke, Mosaic's president and CEO. "He plays an integral role in maintaining our license to operate and Mosaic's environmental, social and governance work, and he drives public affairs strategies that contribute to Mosaic's long-term success."

Mr Pratt was SVP for corporate communications at Ameriprise Financial in Minneapolis immediately prior to joining Mosaic in 2012. Earlier in his career, he held a variety of communications and investor relations roles at PNC Financial Services in Pittsburgh, and at Lehman Brothers and Bear Stearns, both in New York.

Worley has appointed **Chris Ashton** as its new CEO and managing director, following the retirement of **Andrew Wood** from these roles. Chris has held many leadership roles at Worley since joining the company in 1998. He was the company's chief operating officer (COO) immediately prior to becoming CEO. Mr Ashton holds an MBA from Cranfield School of Management and an electrical and electronic engineering degree from the University of Sunderland. He is also a graduate of Harvard Business School's executive management programme.

Commenting on his appointment, Chris said: "It is a great privilege to assume the leadership of this great company. The next decade will see unprecedented change in the energy, chemicals and resources industries which we serve. Our customers are being driven by having to address two fundamental structural disruptions – the energy transition and changes resulting from the adoption of digital processes."

Worley's chairman John Grill paid tribute to the outgoing CEO: "Andrew Wood has had a distinguished career with Worley spanning 26 years, with the last seven as our CEO. His contribution has been fundamental to creating the global company we are today. Under Andrew's strong leadership, we successfully restructured Worley… and then doubled the size of the business through the acquisition of the Energy, Chemicals and Resources (ECR) division of Jacobs. The board and management thank Andrew for his significant and valuable contribution to Worley and wish him well in his retirement."

Nirlep Singh Rai is the new technical director of National Fertilizers Limited (NFL), having previously been the company's executive director. He has also been the CEO of Ramagundam Fertilizers and Chemicals Limited (RFCL) for the past 18 months. RFCL is a prestigious joint venture between NFL, Engineers India Limited and the Fertilizer Corporation of India Limited. Nirlep Singh Rai, a graduate of Thapar University, has 35 years of professional fertilizer industry experience. This includes stints in charge of NFL's Nangal production unit for more than two years, and heading technical services and projects at the Bathinda unit. His experience of large-scale fertilizer plants includes technical services and their operation and maintenance.

Siroj Loikov has been made first deputy CEO of PhosAgro. He was previously the company's deputy CEO in charge of international projects and personnel policy. In his new role, Siroj will act as a management coordinator at PhosAgro's headquarters in Moscow, with particular responsibilities for Cherepovets and the company's other production sites. He will also have control of priority development projects and will oversee the appointment, development and assessment of the company's top management.

Evgeny Novitsky, also first deputy CEO at PhosAgro, will continue in his separate role, liaising between the company and government agencies. **Mikhail Rybnikov**, who has been separately appointed as an executive director, will focus on the integration of production, logistics and sales. He will also oversee the implementation of key IT projects and improvements in industrial safety standards and occupational health at PhosAgro.

Andrey Guryev, PhosAgro's CEO, said: "Today, the company is facing external challenges that require a prompt response and serious international expertise. We have a great deal of work ahead of us to build new partnerships, to implement major international projects. Also on the agenda is in-house projects to digitalise production and to restructure our occupational health and industrial safety functions. Meeting these challenges will require a great deal of commitment and attention. With this in mind, I decided to make some changes to the organisational structure and delegate some of my duties as CEO. I am confident that Siroj Loikov's previous work experience in the company will help him succeed." ■

Calendar 2020

! **The following events may be subject to postponement or cancelation due to the global coronavirus pandemic. Please check the status of individual events with organisers.**

MAY

20-22 **CANCELLED**

IFS Technical Conference,
THE HAGUE, Netherlands
Contact: Steve Hallam
International Fertiliser Society
Tel: +44 (0)1206 851 819
Email: secretary@fertiliser-society.org

JUNE

12-13 **CANCELLED**

44th Annual AIChE Clearwater Conference, CLEARWATER, Florida, USA
Contact: Miguel Bravo
AIChE Central Florida Section
Email: vicechair@aiche-cf.org

SEPTEMBER

14-16

TFI World Fertilizer Conference 2020, WASHINGTON, DC, USA
Contact: Valerie Sutton
Fax: (202)-962-0577
Email: vsutton@tfi.org

OCTOBER

20-22

IFA Crossroads Asia Pacific, SINGAPORE
Contact: IFA Conference Service
49, Avenue d'Iéna, 75116 Paris, France
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

NOVEMBER

2-4

Sulphur and Sulphuric Acid Conference 2020, THE HAGUE, Netherlands
Contact: CRU Events
Chancery House, 53-64 Chancery Lane, London WC2A 1QS
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

16-18

IFA Strategic Forum, KIGALI, Rwanda
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

Weir Minerals staff celebrating the first Lewis® molten salt pump in 2010.

PHOTO: WEIR MINERALS

THEN&NOW

Lewis

Fertilizer International reached its 50th anniversary in 2019. The magazine's continuing success is built on mutually beneficial partnerships forged over five decades. This year, we will continue to show our appreciation by profiling a much-valued commercial supporter in the magazine. This issue it's the turn of the **Lewis®** brand from Weir Minerals.

Lewis began life as Chas S Lewis and Co, Inc, the company established by its founder Charles Lewis in St Louis, Missouri, in 1891. The company, an original equipment manufacturer (OEM) from the start, made pump lines for the beer pasteurisation and bottle cleaning industries using custom alloys.

Lewis developed its first sulphuric acid pump in 1914. As time went on, the company continued to specialise in sulphuric acid equipment and designed the first sulphuric acid valve in 1975. The company was then acquired by Weir Group in 1994 and subsequently expanded its product line.

Company profile

The Lewis® brand from Weir Minerals continues to manufacture reliable specialty pumps and valves for the sulphur, sulphuric acid and phosphoric acid industries, with a reputation for innovative designs and performance over 125 years.

Weir Minerals developed *Lewmet®* nickel-chrome alloys, which are specifically designed to withstand long-term exposure in the harsh operating environment of contact process sulphuric acid plants. Lewis® pumps and valves with *Lewmet®* alloys are able to achieve superior erosion resistance and corrosion protection.

In addition to *Lewmet®*, Weir Minerals added gate, globe and butterfly valves to the Lewis® product line, shipping the first 30" gate valve to Zambian Copper smelter in 1995. These valves have proven to be highly effective in sulphuric acid plants for standard acid and heat recovery services.

50 YEARS ANNIVERSARY 1969-2019

1891
- Chas S Lewis & Co is established by Charles S Lewis as representative for manufacturers of pumps and valves, in St Louis, USA.

1914
- First vertical sulphuric acid pump for chamber acid process is developed and produced.

1970s
- **1972** World class 10-MT/MS (1,200 mt/hr) Lewis acid pump designed and manufactured.
- **1973** First of several *Lewmet®* alloys designed to provide significantly higher corrosion resistance than alloy 20, the material previously used in sulphuric acid applications.
- **1975** Lewis® globe valves introduced for throttling service in hot H_2SO_4.
- **1976** Lewis® gate valves designed and installed for the first time in H_2SO_4 service.
- **1977** Company becomes part of the Baker Hughes Group.

1994
- Weir Group PLC acquires all of Baker Hughes' pump production companies.

2000
- Size 18 acid pump designed, tested and sold.

2010
- First Lewis® molten salts pump is manufactured.

2020
- Three new pumps introduced to the market: New *Lewis® VL Axial Flow Pump*, *Lewis® Horizontal Process Pump* and *Lewis® Vertical High Pressure Molten Salt Pump*.

The latest Lewis® products

Recently, Weir Minerals has developed three new Lewis® pumps for the sulphuric, phosphate fertilizer, and concentrated solar power industries. The *Lewis® VL Axial Pump*, the *Lewis® Horizontal Process Pump*, and the *Lewis® Vertical High Pressure Molten Salt Pump* come in multiple sizes and configurations, and mark a new chapter in the brand's proud history of innovative product and material engineering.

The three pumps are all made with proprietary *Lewmet®* alloys to maximize wear life in some of the world's most corrosive industrial applications while simplifying maintenance through their streamlined designs. This has significantly reduced the number of parts compared to previous pumps, without compromising their performance.

The future of Lewis®

The Lewis® team in St Louis, Missouri, remains dedicated to their customers around the world, and continues to develop pumps, valves, and other related products. For the past 125 years, they have provided equipment that improves safety, efficiency and sustainability, contributing to the essential resources needed by a growing world. Product innovations, a dedicated group of employees, and continued investments in the St Louis community ensure Lewis® will remain a valued supplier to its customers – companies who feed the world and power the global economy.

In 2020, Lewis® and Weir Group will continue to focus on the development of sustainable solutions for customers by concentrating on the sustainability impact of their products. ■

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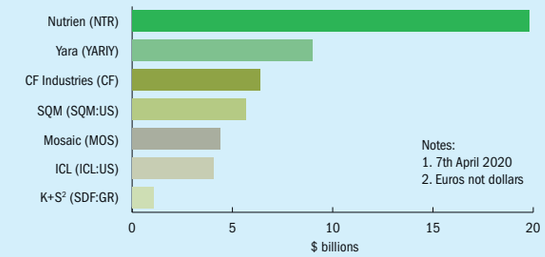
Fertilizer financial scorecard

PHOTO: WHITEMOCCA/SHUTTERSTOCK.COM

We compare and contrast the 2019 financial performance of the major listed fertilizer producers, following the publication of fourth-quarter results.

Fig. 1: **Market captilisation, $ billions, 2020[1]**



Source: YCharts/Bloomberg

Nutrien: stable in a challenging year

Nutrien is the world's largest crop nutrient company with a market capitalisation of almost $20 billion (Figure 1). This fertilizer industry giant produces and distributes over 25 million tonnes of potash, nitrogen and phosphate products for agricultural, industrial and feed customers globally. The company's agriculture retail business also serves over 500,000 growers worldwide through a network of international outlets.

Nutrien summed up its 2019 trading performance with the headline "delivery of stable earnings in a challenging year". The overall picture was certainly solid with the Canadian fertilizer giant reporting slight year-on-year (y-o-y) increases in sales and earnings (adjusted EBITDA) – both up by two percent to $20.0 billion and $4.0 billion, respectively (Figures 2 and 3).

The year didn't end so well, though. Nutrien's potash earnings (EBITDA) fell by more than 60 percent in the fourth-quarter due to lower sales volumes, lower realised selling prices and production curtailments – factors all linked to a global slowdown in potash demand. Similarly, fourth-quarter Nitrogen earnings (EBITDA) were down by almost 20 percent y-o-y. As a consequence, Nutrien posted a net loss of $48 million for the fourth-quarter, despite a strong retail performance.

Rising above these challenges, Nutrien nevertheless generated $2.2 billion in free cash flow – a good measure of overall company profitability – last year, up by almost 10 percent on 2018 (Figure 5).

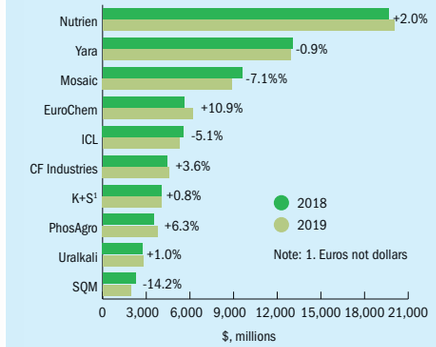
"Nutrien's earnings held up well in 2019 and we generated strong free cash flow in a very tough agriculture market," commented Chuck Magro, Nutrien's president and CEO. "Our business is designed to provide stability in times of market weakness. We remain focused on… allocating capital to grow our retail business and leading our industry in returning capital to shareholders."

Strong earnings growth at Yara

Norway's Yara International managed to strongly grow its earnings to $2.1 billion in 2019, up almost two-fifths y-o-y (Figure 3). Margins improved on lower European gas costs, a more profitable product mix and currency effects.

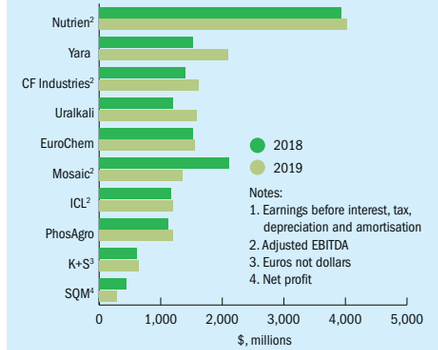
Impressively, Yara's earnings improvement in 2019 was achieved during a year

Fig. 2: **Revenues of selected major fertilizer producers, 2017-2018**



Source: Company filings

Fig. 3: **Earnings of selected major fertilizer producers, 2018-2019[1]**



Source: Company filings

when annual revenues fell slightly – albeit by less than one percent – to $12.9 billion (Figure 2), linked to lower realised fertilizer prices. 2019 results were achieved against a back drop of:

- Five percent lower total sales and deliveries y-o-y, primarily reflecting a nine percent reduction in European deliveries
- Lower fixed costs and six percent higher commercial margins
- A two percent fall in new business deliveries
- A four percent and two percent fall-back in fertilizer and ammonia production, respectively, y-o-y.

Yara reported an "unsatisfactory production performance overall" in the fourth-quarter. Unplanned outages in several ammonia plants (Ferrara, Le Havre, Pilbara) and fertilizer production plants (Porsgrunn, Ferrara, Le Havre) resulted in the loss of 130,000 tonnes of ammonia production and a 220,000 tonne loss in finished fertilizer products. To some extent, this was offset by improved annual production volumes at other production sites in 2019, notably Tertre, Freeport and Belle Plaine, the latter having a record year.

Encouragingly, Yara's free cash flow also emerged from the red during 2019, improving over four successive quarters to reach $863 million by the year's end (Figure 5).

"I'm pleased to see our strategy delivering results and that our free cash flow continues to increase," said Svein Tore Holsether, Yara's president and CEO. "Our free cash flow continues to increase, enabling us to deliver on our capital allocation policy with a substantial dividend increase."

Mosaic takes action

North America experienced its wettest 12 months in almost 50 years in 2019. This negatively affected spring and fall applications and fertilizer sales volumes in the region. This, in turn, pressured prices.

The Mosaic Company, in particular, bore the brunt of these difficult trading conditions. Sales revenues last year fell by seven percent y-o-y to $8.9 billion (Figure 2), while earnings were hit even harder – tumbling by 36 percent to $1.3 billion (Figure 3).

Mosaic ended up reporting a net loss of $1.1 billion for 2019 – reflecting non-cash charges of $1.46 billion. These were incurred from the company's permanent closure of its Plant City phosphates production site, the acceleration of potash production at its Esterhazy K3 mine and extended idling of the Colonsay potash mine.

Such decisive and "aggressive decisions" were entirely necessary, according to Joc O'Rourke, Mosaic's president and CEO.

"In this challenging environment we acted decisively, executed well and strengthened the company's operations for the future, all while delivering record safety results," said O'Rourke. "Our actions to manage our portfolio of assets, lower our cost structure, [and] our reduced inventories… leave us with a tremendous opportunity to capitalize on the improving trends we've seen early this year."

This strategy seems to be paying off for the Florida-headquartered company. Mosaic recently returned its phosphate operations to full production, after good North American demand levels in December and January depleted the company's phosphate inventories. In addition, concerns about product availability have changed market sentiment, in Mosaic's view, driving strong global demand for phosphates.

Sales growth in a milestone year for EuroChem

Higher sales volumes together with more favourable pricing in the first six months of the year lifted annual sales at Swiss-headquartered EuroChem Group to $6.2 billion in 2019, an 11 percent y-o-y rise (Figure 2).

EuroChem's 2019 earnings at $1.6 billion, although lower than originally expected, were also up two percent on 2018 (Figure 3). This improvement was driven primarily by sales growth and the positive effects of the rouble/dollar exchange rate on the company's rouble-denominated costs – the company's production assets being mainly Russian-based. The average rouble/dollar exchange rate rose to 64.7 in 2019 versus a 62.7 average in 2018.

EuroChem's capital expenditure last year reached $950 million, 15 percent lower than in 2018. Overall investment requirements have eased, according to the com-

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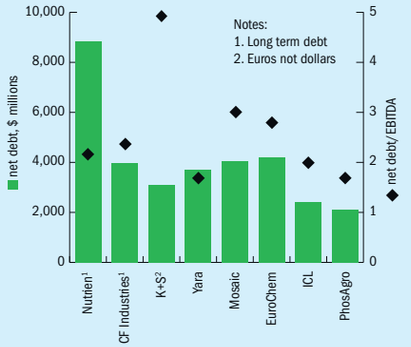
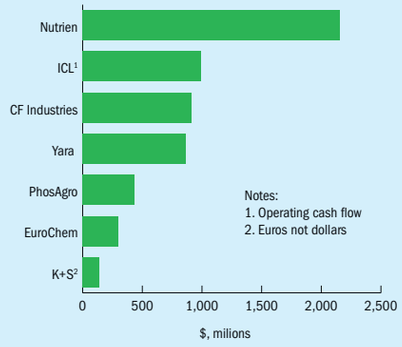
Fig. 4: **Net debt of selected major fertilizer producers, end 2019**



Source: Company filings

Fig. 5: **Free cash flow of selected major fertilizer producers, end 2019**



Source: Company filings

pany, following the opening of the EuroChem Northwest ammonia plant in June last year and the continuing ramp-up of the Usolskiy potash mine over the last 18 months.

EuroChem's net debt-to-earnings ratio increased to 2.8 at the end of 2019 – up from 2.3 a year previously – but remains within industry norms (Figure 4). The company also generated a healthy free positive free cash flow of $297 million last year (Figure 5).

"We have delivered strong full-year results despite the subdued pricing in global fertilizer markets. The beauty of our business model is that it can deliver strong results at almost any point of the commodity industry cycle and that is clearly shown here," said Petter Ostbo, EuroChem's CEO. "2019 was a busy year with a number of major milestones, including the opening of our ammonia plant at Kingisepp, the launch of our updated business strategy, and the continued development and expansion of our distribution platform and new logistics infrastructure. We face the future with great confidence."

Lower potash production and sales at ICL

Israel's ICL Group is a leading speciality chemicals and fertilizer producer with a market capitalisation of around $4.1 billion (Figure 1). The company's annual revenues declined by five percent to $5.3 billion in 2019 (Figure 2). Despite this, full-year earnings rose by three percent y-o-y to $1.2 billion (Figure 3).

Lower potash production – together with the absence of a potash supply contract to China and general commodity market weakness – had a significant impact on ICL's results. The successful completion of a planned potash capacity upgrade at ICL's Dead Sea site, in particular, reduced fourth-quarter production.

Potash contributed to only one-quarter of ICL's sales and one-quarter of adjusted operating income during the fourth-quarter of 2019. In comparison, potash accounted for one-third of sales and almost two-thirds of adjusted operating income over the same period in 2018.

ICL's potash production in 2019 was 721 thousand tonnes lower year-on-year. This was due to lower production at ICL's Dead Sea plant, the shift to polyhalite (*Polysulphate®*) production at ICL's UK Boulby mine, and lower production at ICL Iberia. The quantity of potash sold by ICL in 2019 was also 765 thousand tonnes lower than in 2018. This was primarily due to a decrease in potash sales to Brazil, China and India.

Nevertheless, strong cash generation during 2019 resulted in a 60 percent annual increase in ICL's operating cash flow to $992 million (Figure 5). ICL attributed improvements to both its operating cash flow and earnings in 2019 to its concentration on value-added speciality products, which offer a premium over standard commodities, and the company's focus on cost controls and operational efficiency.

"ICL achieved several important milestones in 2019, the most recent of which was the upgrade of our Dead Sea facilities," said Raviv Zoller, ICL's president and CEO. "While ICL's results for the fourth quarter were impacted by disruptions associated with the upgrade, a weak environment for commodity fertilizers and the unfavourable impact of exchange rates, we believe that the actions we have taken throughout 2019 have significantly strengthened ICL's position and prospects to create value for our shareholders for years to come."

Zoller added: "We also completed the construction of our new food grade phosphoric acid plant in China. That will allow us to shift from commodity phosphates to specialty products."

CF strengthens its balance sheet

North American nitrogen producer CF Industries increased its full-year earnings to $1.6 billion in 2019, up by 15 percent y-o-y (Figure 3). Higher average selling prices across its major products – except in the fourth-quarter – also prompted a four percent rise in 2019 net sales to $4.6 billion (Figure 2).

CF achieved higher average selling prices across most of its nitrogen products in 2019. This was due to a tighter global supply/demand balance, in general, and limited supply at some North American inland locations during the spring application season. At the same time, its cost of sales decreased in 2019, primarily because of lower realized natural gas costs, although this was partially offset by higher maintenance costs.

The Illinois-headquartered company produced a total of 10.2 million tons of ammonia in 2019, setting a quarterly production record of 2.7 million tons in the year's final quarter. Overall, product sales volumes last year were comparable to those in 2018 and 2017, according to CF. Higher fourth-quarter ammonia and ammonium nitrate sales were partially offset by lower granular urea sales.

CF also redeemed $750 million in debt during 2019, lowering its long-term debt to $4.0 billion (Figure 4). The company's free cash flow fell slightly to $915 million in 2019 (Figure 5), down two percent y-o-y.

"The CF team executed exceptionally well in 2019… delivering a 15 percent increase in adjusted EBITDA," said Tony Will, CF Industries president and CEO. "Our 2019 performance and our position on the low-end of the global nitrogen cost curve enabled us to generate more than $900 million in free cash flow [and] strengthen our balance sheet. As a result, we delivered a one-year total shareholder return of 13 percent, which was the top performance in our fertilizer peer group."

K+S achieves earnings growth and positive free cash flow

Germany's K+S increased its 2019 earnings by six percent y-o-y to €640 million (Figure 2), while revenues for the year were stable at €4.1 billion (Figure 3).

The potash and salt producer's 2019 earnings benefitted from higher average prices for potash fertilizers – especially in the year's first-half – compared to the previous year. These gains were, however, partially offset by production cutbacks and higher operating costs.

K+S notably achieved a free cash flow of €140 million in 2019 (Figure 5) – the first time this has moved into the black since 2013 – despite what the company called "cloudy [trading] conditions" affecting the year's second-half.

K+S also paid down debt last year. Its earnings-to-debt ratio decreased to 4.9 at the end of 2019 (Figure 4), down from 5.3 a year previously.

"2019 was another very challenging year for us. Following a good start in the first half of the year, the weakening of the potash market as well as the mild winter in Europe impacted our business development over the further course of the year," said Burkhard Lohr, chairman of K+S. "Despite these adverse circumstances, we nevertheless succeeded in increasing our earnings in 2019 and, as promised, generated positive free cash flow for the first time in six years."

Alongside the release of 2019 annual results, K+S also announced the divestment of its North and South American salt business to pay down debt. The move means K+S will now focus instead on producing and selling fertilizers and speciality products in future,

K+S expects the sale to be agreed by the end of 2020. However, neither the potential buyer for its American salt business or the value of the divestment have yet been disclosed.

"The sale of our strong Americas salt business is a decisive step in setting the course for the future development of K+S. After intensive examination, it is the best option to achieve the urgently required reduction of the company's debt," commented Burkhard Lohr.

The divestment is part of the company's plans to reduce its debt by more than €2 billion by the end of 2021. The decision to exit the salt market in the Americas will also be accompanied by what K+S called a "comprehensive realignment and restructuring" of the company.

"Following the completion of the transaction, K+S will be further developed into a supplier of fertilizers and specialties. No sale of shares in the new Bethune potash plant in Canada is planned," K+S said in a statement.

All business activities and sites retained by K+S will be expected to generate positive free cash flow in future.

"Following the repositioning of K+S, we will be focusing on the expansion of the highly profitable fertilizer specialties business in the subsequent growth phase," Burkhard Lohr signalled.

PhosAgro – revenue and sales growth in challenging times

Russia's PhosAgro is one of the world's leading integrated phosphate fertilizer producers with a market capitalisation of around $4.5 billion.

The company's full-year revenues for 2019 grew by six percent y-o-y to RUB 248.1 billion ($3.8 billion, Figure 2), while earnings for the year were stable at RUB 75.6 billion ($1.2 billion, Figure 3).

Similar to many of its industry peers, PhosAgro's 2019 results were badly affected by fourth-quarter trading conditions. This period saw revenues fall back 11 percent year-on-year to RUB 53.1 billion ($0.8 billion). Earnings took an even greater hit, decreasing by almost 40 percent y-o-y to RUB 11.2 billion ($176 million) during 2019's final quarter.

Despite this, PhosAgro's free cash flow was up 38 percent in 2019, rising to RUB 28.3 billion ($437 million, Figure 5). This improvement was driven by a seven percent y-o-y increase in sales volumes to 9.5 million tonnes, and by more efficient management of working capital.

PhosAgro's financial performance last year enabled the company to fully self-finance its capex programme and improve its debt position. Net debt stood at RUB 131.6 billion ($2.1 billion) at the end of 2019, while its net debt-to-earnings ratio improved slightly to 1.7 (Figure 4), the latter reflecting improved earnings and the rouble's appreciation against the US dollar during the year.

Although a challenging year for the fertilizer industry in general, 2019 was a record year for PhosAgro, according to its CEO Andrey Guryev – when measured by free cash flow, earnings and earnings margin (31 percent).

"Prices for our products came under pressure throughout the year due to adverse weather conditions in key sales markets, as well as increased global supply amid stable demand," Andrey Guryev said. "As a result, prices for phosphate-based fertilizers reached near record lows at the end of the year."

He continued: "Despite the unfavourable pricing environment… PhosAgro was able to increase sales volumes to 9.5 million tonnes. Our strong revenue growth was the result of a balanced approach to investment and maintenance, high levels of self-sufficiency in key inputs, a flexible sales policy and the exceptional quality of our raw materials."

Author's note

In the weeks since fourth-quarter 2019 company results were published in February and early March, the impacts of the *Covid-19* pandemic have deeply affected the outlook for the whole world economy including the global fertilizer industry. For more information, please see our article on *Covid-19* impacts on page 18.

Fertilizer International will continue to monitor market developments during the current crisis period, as we have done throughout our 50-year history.

COMPANY RESULTS

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COVID-19 PANDEMIC

Covid-19 & fertilizers: 5 things you need to know

PHOTO: NHEMZ/SHUTTERSTOCK.COM

CRU's **Laura Cross** guides us through the current Covid-19 crisis and flags up the unique risks faced by the fertilizer industry as the pandemic unfolds.

The Covid-19 pandemic has wide-spread implications for commodity markets, and fertilizers are no exception. The agricultural sector has been caught between a range of conflicting drivers – from the essential nature of food production, to the need to contain the spread of the pandemic. Agriculture has also been hit by volatile foreign exchange rates and the impact of macroeconomic uncertainty on food and biofuels demand. Ultimately, this has started to trickle down and fundamentally affect the cost economics of fertilizer production and the engines of demand.

The increased uncertainty brought about by the Covid-19 pandemic means there are numerous risks to be aware of, many of which are unique to the fertilizer industry. While history tell us that fertilizer demand has proved resilient to prior economic shocks, the industry is not immune to a collapse in the financial system.

The implications for industry financial performance in 2020 – both upsides and downsides – are also mounting, amid an increasingly complex financial markets backdrop. The upside of an already weak fertilizer price environment is better affordability for farmers. This, when coupled with strong crop acreage expectations for 2020, puts demand fundamentals in a robust position for the year ahead, across all the nutrients.

Yet counteracting this, in the first-quarter of 2020 alone, the economy has already needed to contend with:

- A significant shock to the Chinese market
- The spread of Covid-19 westwards and its classification as a pandemic
- The Brent Crude oil price nosediving below $20/bbl
- A subsequent collapse in global financial markets and company share prices.

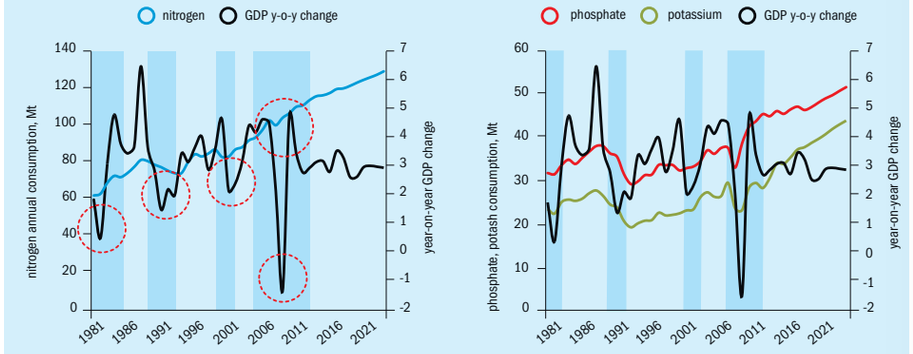
So, what does all this pandemic-induced turmoil mean for the fertilizer market in the coming years? Five unique risks faced by the industry, in our view, are outlined below.

1. Fertilizers are sheltered from near-term economic turbulence, but not immune to recession risks.

Most governments have now classified fertilizers as essential goods, allowing deliveries to farmers to continue despite extensive lockdowns throughout the world. Covid-19 could influence fertilizer markets – and fertilizer demand more specifically – via several mechanisms. People must eat regardless of whether the economy is in an up or down cycle. But the prospect of slower economic growth and the threat of a prolonged global recession can impact fertilizer demand in other ways.

The long-run relationship between nutrient demand and global economic growth

Fig. 1: **Fertilizer consumption is highly inelastic during recessions, particularly nitrogen**



Source: DATA: CRU, IFA

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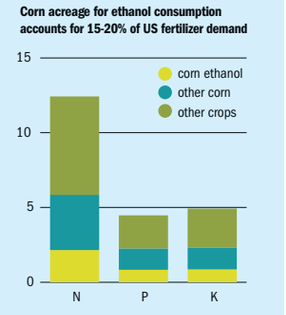
Fig. 2: **Fertilizer demand, Mt nutrient (average 2014-17)**



Source: CRU Market Outlook reports, USDA, IFA

is shown in Figure 1. This shows that fertilizer consumption is relatively inelastic to changes in global economic growth, with historic analysis of previous recessions reinforcing this point. Nitrogen demand is the most inelastic, followed by phosphates and then potash. For the most part, this shields global fertilizer demand from recessionary impacts, relative to other commodity markets. Longer-term demand prospects for all three nutrients remain robust, in CRU's view, albeit with some downside risk to demand in the next crop year.

The effects of the pandemic on the spring season in the northern hemisphere have been limited so far. Farm margins and credit availability are at relatively healthy levels, with planting intentions mostly 'locked-in' despite Covid-19 disruptions. However, beyond this spring season, Covid-19 and its economic repercussions pose a threat to fertilizer markets in three main ways: agricultural commodity price declines, currency devaluations and declining feedstock prices.

2. Crop prices are exposed to commodity cycles, adding delayed bearish sentiment to 2021 demand expectations.

Negative sentiment is combining with expectations of much slower economic growth to create fears over commodity price declines. This is weighing on agricultural commodity prices, especially when coupled with prospects for another large southern hemisphere harvest and a significant rebound in US acreages.

Crop price signals for corn, soybeans and wheat are weakening. Falling crop prices and a potential decline in underlying agricultural demand could dampen fertilizer demand from farmers in the 2020/21 agricultural season. Statistical analysis of previous recessions show that agricultural prices are exposed and closely track commodity cycles. A recession in 2020/21 is therefore likely to mean lower crop prices, particularly for soybeans and wheat, given the relative oversupply in these markets. The downside risk for corn prices is capped by a declining global stocks-to-use ratio and tighter market fundamentals.

The outlook for fertilizer demand beyond the immediate northern hemisphere spring season is subject to considerable risks, these being heavily weighted to the downside. Record acreages and high yields in the US this fertilizer season could result in US corn inventories ballooning to more than three billion bushels by the end of the 2020/21 crop year. This would be even more likely if demand for corn is capped by lower ethanol consumption in the US (Figure 2) and Brazil, driven by reduced economic activity and lower feed demand, the latter linked to livestock/meat price declines.

Fertilizer demand in the fall season will certainly be negatively affected if the above scenario transpires and corn prices decline. In addition, the significant devaluations of the Russian rouble and Brazilian real give the main grain-exporting rivals to the US a cost-advantage. This, in turn, lowers the odds of a strong recovery in US grain and oilseed exports – a key driver of fertilizer demand sentiment.

Despite the relative optimism over demand in the first-half of 2020, there are still some pockets of concern in the near-term – one of these being potash sales into Southeast Asia. Extensive palm oil plantations, mostly located in Indonesia and Malaysia, account for a large slice of MOP consumption. That means changes in the crude palm oil (CPO) market affect Southeast Asian demand for potash and influence its pricing.

Southeast Asian MOP demand contracted 21 percent year-on-year in 2019. Nevertheless, high CPO prices towards the end of last year had spurred hopes of a rapid rebound in 2020. Instead, the macroeconomic impacts of the Covid-19 pandemic have wiped out almost all the gains CPO prices made in late 2019. Potash purchasing activity across the region has also slowed to a crawl in recent weeks, exacerbated by restrictive measures placed on the movement of people and goods as Covid-19 cases have risen rapidly.

3. The energy market backdrop is as important as ever.

A triple collapse – in oil prices, industrial consumption and key exchange rates – has distinct downside effects for fertilizer feedstocks. This is especially true of nitrogen producers, as spot gas prices in Europe and the US, along with coal prices in China, continue to decline. A drop in cargo shipments and lower bunker costs (these accounting for around 50 percent of freight costs) are likely to maintain pressure on freight rates.

The unprecedented decline in the US WTI crude oil price in April has raised the prospect of meaningful cutbacks in US oil output. This will result in a drop in associated gas production, tightening the natural gas balance and potentially raising the Henry Hub gas price above current forecasts. However, this is countered by an increasingly shaky energy demand outlook as the Covid-19 pandemic takes effect.

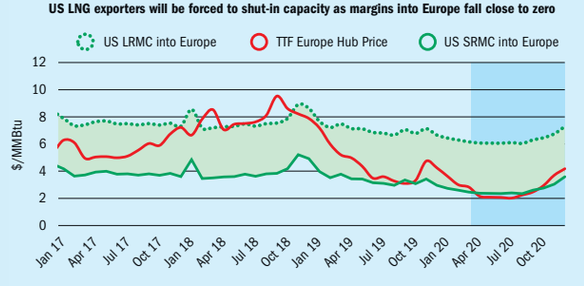
Oil prices are now expected to stay in the $15-$25/bbl range during the second-quarter of 2020 as we move through the trough in demand. Despite this, only about 30 percent of the nitrogen cost curve is now linked to the oil price. China, India, and a few other countries East of Suez still buy at an oil-indexed gas price, meaning these select countries will benefit from lower feedstock costs if the lower oil price is sustained. This 30 percent does not include producers supplying the marginal price-setting tonnes but will change the shape of the nitrogen industry cost curve.

The gas price paid by most nitrogen producers is instead government-regulated and not linked to the oil price. Oil and gas markets are also largely decoupled. The declining oil price is therefore expected to have a limited impact on spot gas prices. Gas markets are already oversupplied, and as a result prices are expected to continue declining in 2020.

A global glut of natural gas has seen prices plunge in the US, Europe, and Asia in the last two years as a wave of liquefied natural gas (LNG) hit the market (Figure 3). In the first four months of 2020, the Covid-19 pandemic has dented natural gas demand due to industrial outages and travel restrictions. The mild winter in the northern hemisphere has added even more pressure on prices. It has also left European storage sites almost full, which will translate into record low injections this summer.

These bearish fundamentals mean that spot gas prices are forecast to continue to slide until they reach a point where it no longer makes financial sense to sell into the European market. CRU does not

Fig. 3: **Natural gas prices & marginal cost of US LNG deliveries into Europe, $/MMBtu**



**The Long Run Marginal Costs of US LNG (full cycle costs) is calculated as the Henry Hub* 115% + liquefication and regasification costs. The Short Run Marginal cost (SRMC) covers only the variable costs into Europe.* *Source: CRU, Bloomberg, EIA*

expect a meaningful recovery in gas prices until 2021, this being contingent on:

- Demand recovering by the fourth-quarter of 2020
- Marginal LNG exports being cut back in the US
- A degree of discipline in Russian pipeline export volumes.

CRU forecasts the TTF Europe Hub Price to average $2.90/MMBtu in 2020, down from $4.45/MMBtu in 2019 (Figure 3). The consensus view is that the gas price floor in Europe is quite difficult to call, with a significant risk of the TTF falling below $2/MMBtu and staying there in 2020. This is likely to happen if swing LNG exporters do not pull back – and, more importantly, if the Covid-19 enforced lockdown in Europe remains in place until the third-quarter of 2020.

This upshot of all of this is substantially lower production costs for nitrogen producers in Western Europe, now positioned in the first-quartile of the urea exporter cost curve, a dramatic overhaul from the region's traditional cost economics. It also means that Eastern European producers – previously in the last-quartile of the exporter cost curve – now have lower costs too, with an increasing number of producers in this region paying a gas price that is tethered to the TTF spot hub price.

Furthermore, the lower oil price has an impact on fertilizer costs in countries such as Russia, where the exchange rate is linked to the price of oil. The Russian gas price, being rouble-denominated, will also lower nitrogen feedstock costs in equivalent US dollars. This makes Russian nitrogen producers more competitive in the international ammonia market where exports via the Black Sea play an important role in price-setting.

Marginal costs in the urea market, meanwhile, continue to be set by coal-based Chinese exporters. Although not being affected directly by lower oil prices, they are also seeing their costs decline as a result of an oversupplied coal market.

This energy market backdrop also affects sulphur supply. The sulphur market started 2020 with weak demand and oversupply, with projections of further supply growth. The Covid-19 outbreak has reset both supply and demand expectations, although the dent in supply, particularly from oil refining, is now expected to be most severe.

Oil refining has been hit by both a reduction in product margins and, more importantly, by a collapse in oil product demand. Much of the refining sector had originally adopted an approach of business-as-usual during the first-quarter of 2020. But that sentiment has now shifted.

The global view of the contraction in oil demand in 2020 has been shifting rapidly as the Covid-19 outbreak has evolved. The most recent forecast by the US energy agency EIA estimates global oil demand to decline by around five percent year-on-year for 2020. These demand losses are, however, expected to mostly occur during the second-quarter. The EIA's estimate of 101 million barrels per day (Mbpd) oil demand in 2019 is forecast to fall to just 85 Mbpd in April 2020. Sulphur production from oil refining will track these falls in oil consumption. This will significantly tighten sulphur supply in Europe, US, and Japan/South Korea in 2020's second-quarter.

4. Currency fluctuations are driving a cost and affordability shift.

In March 2020, the global economy suffered the dual shock of the Covid-19 contagion and an oil price collapse. As governments implemented stringent restrictions on the movement of citizens, and while Saudi Arabia and Russia battled over oil market share, foreign capital that had previously flowed into developing nation economies during 2019 suddenly retreated. As investors fled to traditional safe havens, such as gold or US government bonds, many of the major developing nation currencies depreciated sharply against the US dollar.

Changes in foreign exchange rates impact fertilizer production costs and fertilizer affordability. The industry is heavily exposed to four major economies: Brazil, Russia, India and China – commonly referred to as the 'BRIC' economies. All four are major producers and consumers of fertilizers. The volatility in foreign exchange rates in these countries could significantly disrupt the market's underlying price support, as production costs in US dollars are lower for BRIC exporters. Fertilizer importers in BRIC countries, meanwhile, face higher prices in local currency.

In terms of both capacity and demand, the BRIC economies account for nearly 50 percent of the key fertilizer industry products across nitrogen, phosphate, and potash markets (Figure 4). For individual fertilizer products, the impact of shifting exchange rates will vary depending on its geographical supply and demand structure.

As Covid-19 and plunging oil prices have rocked the global economy in 2020, local currencies in key fertilizer production and demand regions have depreciated rapidly. Three of the world's largest fertilizer markets – Russia, India and Brazil – have witnessed some of the most profound currency devaluations. For domestic fertilizer producers in these countries, weaker local currencies can boost their margins by lowering operating costs in US dollars, but only those integrated with raw materials will be able to take full advantage.

In key fertilizer importing regions, local currency depreciation affects affordability by raising purchase costs. This exerts a downwards pressure on both fertilizer demand and US dollar-denominated fertilizer prices. While isolated currency depreciation, in a single or a select few countries, can work to the benefit of producers, widespread depreciation forces prices downwards as cost floors decline and import prices in local currency rise.

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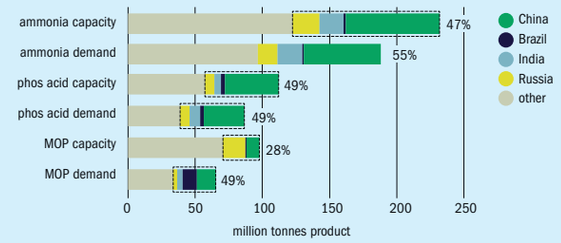
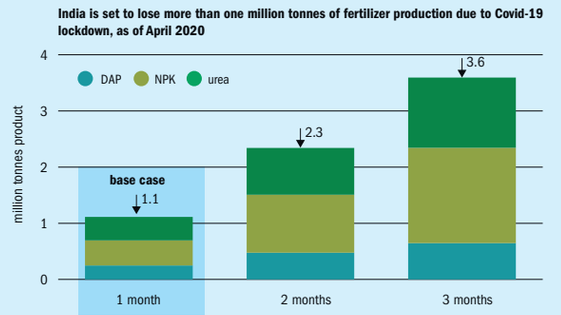
Fig. 4: **Capacity/demand forecast for BRIC* economies by product in 2020**



** BRIC: Brazil, Russia, India and China. These four countries produce or consume nearly 50 percent of key fertilizer industry products.*
Source: CRU Ammonia, Phosphate Fertilizer and Potassium Chloride Market Outlooks

Fig. 5: **Lost fertilizer production in India as a direct result of Covid-19 restrictions**



Source: CRU

5. India has been one of the hardest hit fertilizer markets due to Covid-19 lockdown. On the supply side, the Covid-19 outbreak in China caused temporary production losses due to quarantined labour, supply chain disruptions and other restrictions. Fertilizer production in China is, however, now reportedly back to normal levels. Indeed, following the end of China's domestic application season in mid-May, exports from the country – a marginal producer – are expected to ramp-up, pressuring nitrogen and phosphate fertilizer prices.

At the time of writing, most countries outside of China are implementing national lockdowns to varying degrees. But this appears unlikely to significantly disrupt fertilizer supply and logistics globally. Instead, because most governments have classed fertilizers as essential goods, major supply chain disruptions have been largely avoided.

India has been a key exception to this. The strict Covid-19 lockdown on the subcontinent led to logistics bottlenecks and, ultimately, widespread plant closures and low utilisation rates. As one of the most crucial centres of global demand for nitrogen and phosphate fertilizers, a slowdown in domestic Indian production has implications for the global market. We consider these in detail below.

India began three weeks of lockdown on 25th March, later extended into May. The limited manpower and logistic bottlenecks that happened as a consequence of this have halted operations at many industrial production sites. While fertilizers have been classified as essential commodities, and DAP, NPK and urea plants continue to operate, low utilisation rates are acting to limit productivity. As well as this, at least eight of India's major ports have been closed at some point under *force majeure*, a measure likely to herald further supply chain disruption.

India is a major producer of urea, DAP and NPK fertilizers. As of April, eight of India's 13 DAP production units and 14 of its 17 NPK production units were idle as a result of lockdown measures. We expect those phosphate plants still operating to continue to run at low utilisation rates, hampered by logistics issues and labour shortages, until lockdown measures are eased. Six of India's 32 urea plants were also idle in April due to lockdown measures. CRU has calculated domestic fertilizer production losses based on whether India's lockdown lasts one, two or three months (Figure 5).

Supply-side disruption is only half the story. India also faces the risk of demand destruction as a result of Covid-19, counter to previous expectations of a strong fertilizer demand outlook for India in 2020. Prior to the pandemic, CRU's view was that Indian fertilizer consumption would be strong in 2020 – building on its resilient 2019 performance in what was generally a poor year for global fertilizer demand.

Across the major products, Indian fertilizer demand reached a record 57.7 million tonnes in 2019. This was underpinned by a strong rise in urea and DAP consumption last year. Demand remained robust through the second-half of 2019 due to high monsoon rainfall late in the season. MOP was the only fertilizer to see a decline in consumption last year, linked to the lower affordability of potash and product substitution. NP/NPK sales, in contrast, were buoyed by improved affordability, particularly for high-value fruit and vegetable crops.

At the time of writing, we forecast a marginal downward correction in total Indian fertilizer demand for 2020 – a fall of 1.2 percent year-on-year to 57.0 million tonnes – with the caveat that Covid-19 disruption remains a significant downside risk.

Looking ahead

In summary, the fertilizer market is currently in a state of flux as governments, producers, retailers and end-users make adjustments in response to the pandemic. So far, the fertilizer industry has dealt with the Covid-19 contagion remarkably well, given the possible supply-chain disruptions resulting from lockdowns. This remains an unfolding and evolving crisis, however. All eyes, therefore, will now be on the resilience of the market over the next 12-18 months. ■

Digitalisation and big data

Digitalisation and the analysis of big data are playing an increasing role in fertilizer production. Innovative digital and cloud-based services are being offered by a range of technology companies, including Casale, tkIS, Topsoe and TOYO.

Chemical plants generate huge amounts of data every single day. Raw data needs to be analysed and converted into useful and actionable knowledge to get the full benefit from this wealth of information. Most of the time, however, only the most critical and prominent performance indicators are generally analysed by plant operators due to lack of internal resources and/or specific expertise.

Fortunately, digital technology now exists to capture, transfer and analyse huge amounts of data. This transition from the analogue to the digital – digitalisation – is opening up new opportunities for chemical plants, such as remote plant monitoring, remote plant operation and the real-time interpretation of plant data.

A raft of new digital technologies are currently being introduced by businesses as part of the so-called fourth industrial revolution – also known as 'Industry 4.0'. These include the internet of things (IoT) artificial intelligence (AI), machine learning and cloud computing.

One digital innovation in particular – the IIoT (industrial internet of things) – holds great potential for the chemical industry. Cloud-based IIoT systems, when securely connected to chemical plants, can generate algorithms for process optimisation and predictive maintenance.

In this article we report on the digital services being offered by a number of leading technology providers to the fertilizer industry. These are designed to improve both plant efficiency and reliability.

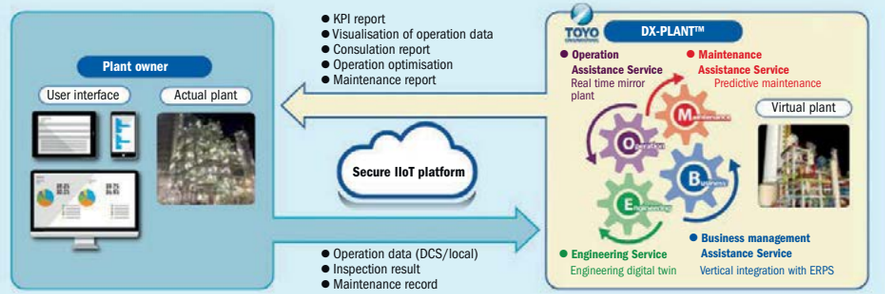
TOYO's digital approach – *DX-PLANT*™

TOYO believes the IIoT will be at the core of the fourth industrial revolution that looks set to usher in a range of exciting new changes to the way fertilizers and basic chemicals are manufactured. The Japanese company – a leading global engineering contractor and urea process licensor – has developed a system for the digital transformation of plants known as *DX-PLANT*™ (*Nitrogen+Syngas* 360, p50). This system leverages TOYO's unrivalled engineering expertise in chemical process technology and industrial plant operations. *DX-PLANT*™ is designed to maximise customer revenues and minimise their costs. It achieves this by providing services via a secure digital platform (Figure 1).

DX-PLANT™ works by creating a 'digital twin' – a virtual plant synchronised with an actual plant – based on big data captured from industrial plants. The *DX-PLANT*™ system enables TOYO to provide services and solutions to plant operators in four specific areas (Figure 2):

- **Engineering (E)**: information management via an engineering 'digital twin'. This 3D model platform uses augmented reality (AR) and virtual reality (VR) applications.
- **Operations (O)**: this offers real-time process prediction/optimisation, including plant conditions monitoring and anomaly detection, using both real instruments (for pressure, temperature, flow etc.) and 'soft' sensors.
- **Maintenance (M)**: this substitutes conventional periodic maintenance at set times with a more responsive conditions-based digital maintenance regime. Maintenance frequency and intervals are set by real-time monitoring and the prediction of abnormal conditions, for both rotating machines and static equipment.

Fig. 1: **DX-PLANT™ architecture**



Source: TOYO

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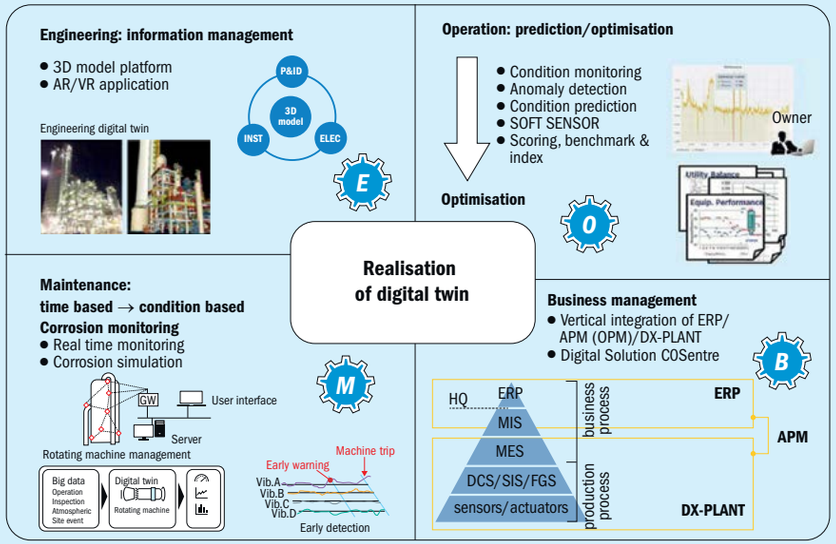
Fig. 2: **E/O/M/B concept of DX-PLANT™**



Source: TOYO

TOYO offers a corrosion simulator, online ultrasonic (UT) monitoring and online metallic ion (Fe, Cr and Ni) monitoring as part of its digital maintenance package.

- **Business (B)**: this company-wide approach combines corporate and factory management using stored operation and maintenance information. This service integrates *DX-PLANT*™ with enterprise resource planning (ERP) and asset performance management (APM).

TOYO began development of *DX-PLANT*™ in November 2016 in collaboration with GE (now Baker Hughes, a GE company). TOYO's system was originally based on an evolution of GE's *Predix* cloud-based platform for industry.

However, following a dialogue with several plant owners – and to help satisfy end-user requirements – TOYO decided to expand the *DX-PLANT*™ line-up by developing its own self-made and in-house additions to the existing GE *Predix* platform. These new add-ons allow end-users to modify the system. This flexibility is valued, according to TOYO, as it permits clients to adapt and manage *DX-PLANT*™ more easily.

Further development of *DX Plant*™

TOYO launched *DX-PLANT*™ on the market in December 2017 by installing the system at the operations of Indonesian urea producer PT Pupuk Sriwidjaja Palembang (PUSRI). Further deployments of *DXPLANT*™ are imminent at several other plants during the next phase of its development,

Looking ahead, TOYO plans to expand *DX-PLANT*™ applications to encompass other types of petrochemical plants and other industries. TOYO also intends to establish a 'Digital Solution Centre' once several plants are connected on the *DX-PLANT*™ platform. By connecting together multiple plants, this will provide a total solution to end-users. TOYO's believes its integrated IIoT-based service sets a new benchmark for fertilizer plant governance.

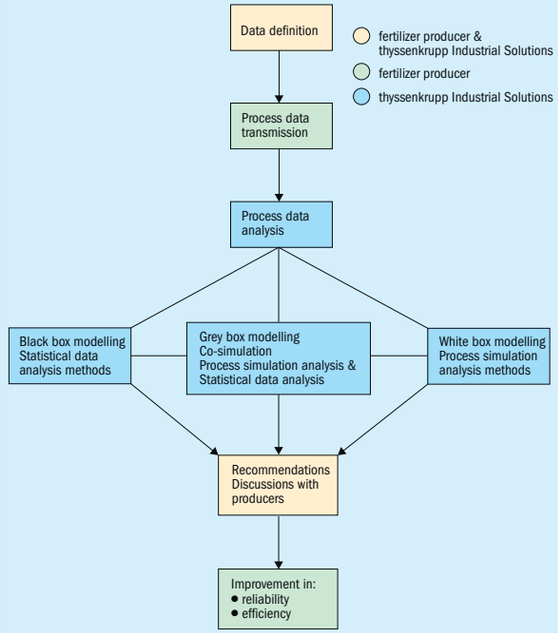
tkIS – big data analysis at ammonia-urea plants

The control of manufacturing plants via a mobile phone is not generally the aim of fertilizer producers. Yet mobile devices do enable engineering employees to access plant data from remote locations so they can check the plant's status and provide recommendations to operators inside the plant.

The same plant data being selectively accessed by production workers on mobile devices could also be transmitted as a whole to a process licensor like thyssenkrupp Industrial Solutions (tkIS). Such licensors have the necessary technology know-how and expertise to analyse and interpret the plant data and generate a detailed report about the status of the plant. These reports can provide fertilizer producers with recommendations and targets for improving plant reliability, increasing production or improving energy and water efficiency.

tkIS has experience and expertise in big data analysis covering several industries (*Nitrogen+Syngas* 354, p32). This has enabled the German engineering giant to improving plant performance and output for their customers, and solve specific process problems on their behalf. thyssenkrupp's approach to big data analysis has been successfully tested at an ammonia-urea plant in Egypt. Based on the positive results obtained, tkIS says it will continue offering analytical services for process

Fig. 3: **Modelling methods for plant data analytics**



Source: tkIS

data to its own customers – and expand this to include other ammonia-urea plants that use third-party technology.

tkIS offers several options for big data analysis at industrial plants (Figure 3):

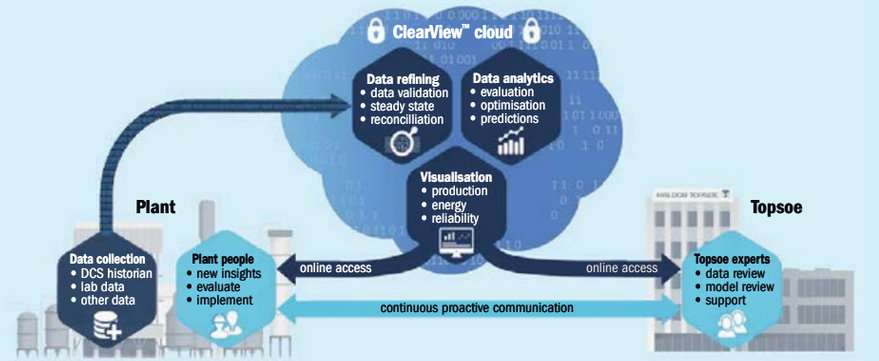
- **White box modelling**: a detailed plant simulation (e.g. *Aspen Plus*®) collates and interprets a large amount of process data from the plant and uses this to create a 'digital twin'.
- **Black box modelling**: this is a process simulation carried out without any deep knowledge of the plant. This approach can also be used for process optimisation and to detect process abnormalities It can also set targets in terms of efficiency and reliability, e.g. by finding critical parameters which might cause a plant to trip and so prevent this from happening.
- **Grey box modelling**: This third option for plant analysis is a co-simulation that combines both white and black box modelling approaches. The results of the detailed plant simulation, run to match the real-time plant data, are transferred back into the process simulation.

ClearView™ from Topsoe

The *ClearView*™ software system offered by Topsoe is based on the automatic upload of plant operating data to an IIoT platform (Figure 4). This system is designed to help ammonia producers harvest data and realise the full potential of their

Fig. 4: **Illustration of Topsoe connected services solution: ClearView™**

Source: Topsoe



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plants. *ClearView*™ creates a 'digital twin' of the ammonia plant in the cloud and uses this to provide plant personnel with best-practice knowledge on a daily basis (*Nitrogen+Syngas* 360, p46).

ClearView™ combines data validation with cloud-based simulation tools and data analytics software to evaluate and optimise plant operations. The system also benefits from a vast library of technical information held by Topsoe. This includes rigorous proprietary models, deep domain knowledge and the company's extensive experience of catalysis and process design.

The results obtained from *ClearView*™ are visualised through online dashboards, these giving plant personnel a clear overview of how to optimise plant operations. The dashboards show, for a given operating variable, shortfalls between the current level and the optimal setting for that variable. Optimisation is achieved by monitoring catalyst and equipment performance, and by tracking and improving the plant's overall key performance indicators (KPIs). Additionally, an early event detection feature helps to avoid downtime from unplanned outages. The software is easy to use and does not require extensive training.

The online dashboards are designed to deliver up-to-date information and insights directly to the relevant personnel. Usefully, they can be customised to match the roles and responsibilities of particular staff. They can provide the CEO and plant manager with a summary of the plant's overall status and KPIs, for example, or show at-a-glance alerts for the daily shift engineer, or give a more detailed optimisation update to the technical department. Plant performance data is also monitored by Topsoe experts so they can provide continuous support to plant personnel. This helps company engineers to pursue optimisation opportunities, and respond to reliability-related alerts, as early as possible.

The best practice guidance, background information and theory embedded in *ClearView*™ software can also be used to develop the competency of operators and engineers. The software can give less experienced personnel a more fundamental and better understanding of how the plant operates.

What *ClearView*™ can do

ClearView™ is able to identify achievable opportunities for plant optimisation. The software flags up what operating parameters need to be adjusted (feedstock parameters, production output, energy consumption etc.) for the plant to reach optimum performance. It also provides short-term monitoring of plant performance and health, e.g. by detecting hydrocarbon cracking, condensation on catalysts, large exchanger leaks etc. Similarly, it can also monitor long-term performance degradation issues such as catalyst deactivation, equipment fouling, pressure drop, turbine inefficiency etc. In doing so, the software avoids costly downtimes by detecting and solving process issues before they become critical.

Topsoe-Honeywell alliance

Topsoe has entered into a strategic alliance with Honeywell, a company with considerable expertise in developing software for the oil and gas industry. Honeywell already provides cloud-based software services – Honeywell Connected Plant Services – to more than 70 refinery units globally. Topsoe's *ClearView*™ service uses the same IIoT platform and user interface as Honeywell. The lessons learned by Honeywell from the first 2-3 years of commercial operation of its platform are also being incorporated into *ClearView*™. This will allow Topsoe to improve and maximise the service offered to its ammonia and syngas plant customers.

Easy implementation and low maintenance

Topsoe offers *ClearView*™ to its customers as a complete end-to-end service. This removes responsibility from plant operators for implementing and managing a large, complex IT project. The hassle of maintaining models, software and IT infrastructure is also avoided. Everything related to system maintenance, migration, updates, backups and recovery is covered by the *ClearView*™ service.

Time and plant resources are also saved as only a limited on-site commitment and no large initial investment is required to get the service up and running. This enables plant personnel to instead focus on the information and support provided by *ClearView™* and take full advantage of the service offered.

ClearView™ is kept up-to-date and its functionality maintained by continuous improvements to the online dashboards and underlying calculations. The latest enhancements are provided through online updates as they become available.

Innovative digital solutions from Casale

Casale has developed two best-in-class digital products for industrial plant operations. Casale remote engineering services (CARES) analyses and interprets plant operating data to enhance its value. Model predictive control (MPC), meanwhile, is a real-time advanced control system for improving plant performance (*Nitrogen+Syngas* 354, p32).

Both digital products are built around customer needs. CARES allows operators to remain the pilot of their plant, combining full control of operations with expert advice from Casale at their disposal. Casale's fully automated MPC system, in contrast, is essentially a trusted auto-pilot that offers maximum plant performance at all times. Both CARES and MPC can be applied to any fertilizer industry process and methanol production.

Casale remote engineering services (CARES)

CARES is an innovative digital offering designed to help plant operators and managers achieve their daily production targets – by boosting plant production or minimising consumption and emissions. CARES employs sophisticated numerical methods and proven proprietary simulation technology to provide the following benefits to plant owners:

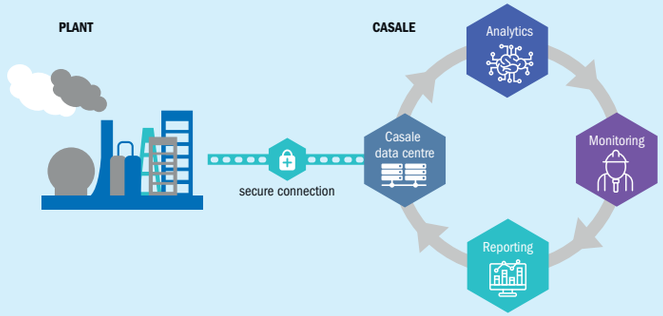
- **Operational advice** from Casale experts on improving plant performance.
- **Better performance indicators** for the whole plant and for single equipment items.
- **Prevention of shutdown and equipment failures** by early detection of malfunctions.

CARES acts as a personal advisor for operators when they troubleshoot process upsets. When looking at the operational data, it can also advise operators on when to carry out mechanical inspections, as part of a pro-active maintenance programme. Monitoring the close relationships between process operations and mechanical reliability is one of CARES key functions and main priorities.

In-depth analysis of plant data by CARES creates a 'virtuous circle', according to Casale. Raw plant data are processed at the Casale Data Center – where it gets cleaned, corrected and augmented – creating valuable information that is then placed at the disposal of clients.

> **One of CARES main strengths is that it combines the digital and the human – by integrating powerful algorithms with the experience of Casale's team.**

Fig. 5: **Four functions of Casale's remote engineering services (CARES) package**



Source: Casale

One of CARES main strengths is that it uniquely combines the digital and the human – by integrating powerful algorithms with the experience of Casale's team. The service is based on four separate components (Figure 5):

- **Data transfer:** This takes place between the plant and the Casale Data Center via a modern seamless one-way connection. This allows plant operators to profit from the plant data without compromising operational security.
- **CARES Analytics:** the raw plant data undergoes deep and professional analysis to reveal its true value. This is accomplished through the uses of proprietary thermodynamic and kinetic models. Data robustness is enhanced (by mass and e nergy data reconciliation) to reduce the effects of measurement errors or lack of instrumentation. A meaningful and unique set of key performance indicators (KPIs) is computed – these being tailored to each plant and individual customer needs.
- **CARES Monitoring:** CARES is much more than a remote monitoring software – it offers a true remote engineering service. Behind the scenes, a dedicated team of Casale engineers closely monitor plant performance. Monitoring is followed up by the necessary next steps arising from the data analysis, with suggested actions encompassing plant optimisation, pro-active maintenance or troubleshooting.
- **CARES Reporting:** The ability to provide the plant's operational team with effective feedback is an essential function of a remote engineering service. CARES does this by offering two-fold reporting. Firstly, a web dashboard provides a quick and effective visualisation of plant performance. Secondly, reports issued to operators on a regular basis provide a much more detailed engineering analysis. The dashboard comes equipped with 'assistance chat'. This allows operators to immediately link up with Casale specialists, whenever necessary. On top of this, conference calls are also regularly organised for in-depth discussion of process optimisation. Finally, plant events, such as extra-routine operations, are recorded and tracked in chronological sequence by the system's 'plant event notification' interface.

Model predictive control (MPC)

Casale's model predictive control (MPC) system was developed in response to a growing demand from plant operators to increase production, maintain stability, and reduce energy consumption and emissions.

Even the most experienced operator is not able to adjust plant parameters rapidly enough to respond to plant fluctuations or external disturbances. As a result, plants are often operated far below their maximum achievable performance.

According to Casale, MPC "pushes the process out of the comfort zone of the plant operators". The aim is to move the plant as close as possible to its optimum performance – while always respecting operating limits/constraints, particularly process and mechanical safety.

MPC is an automated system that complements the plant's distributed control system (DCS). MPC continuously calculates the optimum set point of a number of chosen variables to keep plant performance at maximum at all times. Once stabilisation is achieved, MPC can safely push the plant's performance, achieving higher production while reducing its energy consumption.

By partnering with accomplished and recognised software providers, including Honeywell, Yokogawa and Rockwell Automation, Casale is able to offer a dedicated MPC product for all fertilizer industry process technologies.

MPC is able to interpret the complex phenomena observed in fertilizer plants by incorporating customised thermodynamic and kinetic models. Fertilizer plants – including those used to produce urea, melamine, nitric acid, ammonium nitrate, ammonia, etc. – exhibit large recycle streams. These affect the performance of the synthesis section and the operational stability of the plant.

MPC has been designed to handle these strongly non-linear types of system, being able to identify and target the optimum values of critical process control variables. These optimum values are not steady-state figures. They dynamically change at each plant, depending on the real-time capabilities of the recycling system. MPC pays attention to each and every need of an operational plant at any time. It therefore offers a highly efficient service without any real compromises. ■

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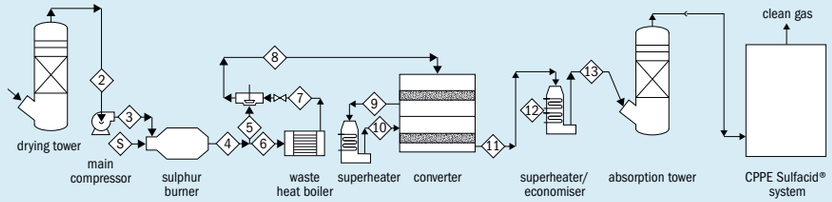
Sulphuric acid plant design and materials

We highlight recent innovations in sulphuric acid plant design and construction. NORAM and CPPE are offering a new hybrid sulphuric acid process. KVT, meanwhile, has upgraded its wet sulphuric acid technology to reduce capex, opex and emissions. Improved methods of construction and new materials from Koch Knight are also helping to optimise acid tower design

Fig. 1: **Example of a HSAP sulphur burning plant**

Source: NORAM



Increasingly stringent emissions regulation are an increasing challenge, both for currently operating sulphuric acid plants and those under development. To help meet new emissions targets for sulphur-containing gases, NORAM in partnership with CPPE have introduced the Hybrid Sulphuric Acid Process (HSAP).

Environmental and other challenges

Environmental regulations worldwide have become increasingly stringent with narrower operating limits and increasing penalties for non-compliance. There is a requirement for all sulphuric acid plants – sulphur-burning, metallurgical, acid regeneration or acid gas types – to achieve very low steady-state emissions of less than 50 mg/Nm³ (SO_3, H_2SO_4 mist and SO_2). Low emissions limits must also be met and maintained during start-up and process upsets. Plants also need to be able to continue manufacturing sulphuric acid to commercial specifications while complying with these environmental constraints.

Other important operational considerations and design challenges at sulphuric acid plants include:

- **Chemical integration.** Any scrubbing processes that can be integrated to produce commercial-grade sulphuric acid are attractive to operators.
- **Energy recovery and efficiency.** The economics and the sustainability of large-scale industrial operations ultimately depend on energy efficiency. Processes that offer improvements in energy recovery are therefore desirable.
- **Operability.** Operators place great store in processes that are safe and whose mode of operation is well understood.

The HSAP process

To address and overcome these challenges, NORAM and CPPE formed an exclusive alliance to develop the Hybrid Sulphuric Acid Process (HSAP). This innovative process provides a comprehensive solution for the abatement of SO_2 gases in industrial applications (*Sulphur* 383, p44).

HSAP increases the production of sulphuric acid and steam while at the same time reducing SO_2, SO_3 and H_2SO_4 emissions – and does this without requiring additional reagents or raising operating costs.

HSAP is based on standard single-contact, single-absorption sulphuric acid technology. It combines modern NORAM equipment designs with CPPE's *Sulfacid*® reactor. In the process, acidic effluent from the *Sulfacid*® reactor is recycled to the contact section in a closed loop. This is advantageous as it avoids the need for added chemicals and eliminates waste by-products.

An example of a HSAP plant for sulphur-burning applications is shown in Figure 1. Ambient air is fed to the drying tower to remove moisture. Using the main plant blower, dry process gas is then fed into the sulphur-burner to produce hot SO_2 gas. Excess heat is removed via the steam system to generate steam and/or power. A catalytic converter with inter-bed cooling converts SO_2 gas into SO_3. This is then absorbed in the absorption tower and finally processed by the *Sulfacid*® system to produce diluted acid (Figure 2).

In the *Sulfacid*® system, raw gas is treated as it flows through a fixed bed of activated carbon catalyst inside the reactor. Wet catalysis converts SO_2 into sulphuric acid at high efficiency in the presence of oxygen and water. The resulting water-saturated clean gas is discharged to atmosphere via a stack. Water is sprayed over the catalyst intermittently to wash out sulphuric acid collected in pores and on the surface. The clear industrial-grade sulphuric acid obtained flows into a buffer tank.

HSAP – benefits, features and advantages

HSAP is notable for the following key features and benefits:

- Plant design can be adjusted to meet tight emission standards
- The system can tolerate process fluctuations while maintaining low emissions
- No gas re-heat is required – resulting in higher energy recovery from the process gas
- The gas system's lower pressure drop can be realised as a blower power saving or by increasing capacity
- No scrubbing chemicals are required
- The *Sulfacid*® system is catalytic and does not consume chemicals
- The activated carbon catalyst has a long operational life
- No by-products are produced
- The dilute acid product from the *Sulfacid*® system is fully-utilised in the contact plant as dilution feed.

Project implementation

HSAP is offered by CPPE-NORAM as a single integrated system. The two companies are able to provide the complete HSAP plant, make all the necessary modifications to the contact plant, and offer a single guarantee for the complete hybrid system.

HSAP can be applied to new plants or retrofitted to those currently operating. It achieves lower SO_2 emissions than double absorption systems and can match the performance of other off-gas treatment options. HSAP has very low operating costs, low maintenance requirements and is easy to operate. Minimal operator training is required and the technology and equipment are well known to plant engineers and operators.

The plant can also be designed to meet the requirements of future emissions regulations. Additional *Sulfacid*® activated carbon catalyst can be added to the equipment, if further emissions reductions prove necessary after installation, without major cost impacts or down time.

Additionally, the system's ability to cope with fluctuations in SO_2 concentration and flow offers operational and environmental benefits. HSAP is less sensitive to fluctuations in SO_2 load that occur during process upsets because activated carbon in the *Sulfacid*® process acts as an absorption 'sink'. This allows HSAP to reduce start-up emissions, achieve faster start-up times and accept a wider SO_2 concentration range during operation – without any impact on plant emissions.

KVT Process Technology (KVT)

KVT Process Technology (KVT) has upgraded its wet sulphuric acid technology to improve plant efficiency in a wide range of settings. Indeed, the company's *OXYSULF* process sets a new benchmark in the desulphurisation of waste gases. This energy-efficient,

SULPHURIC ACID TECHNOLOGY

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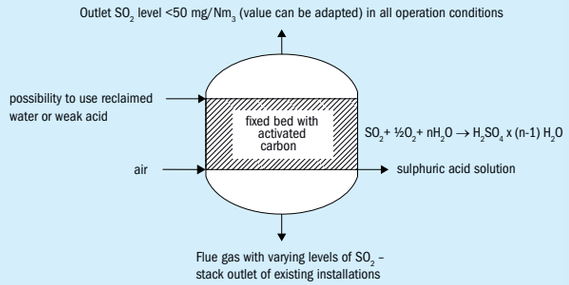
zero waste process achieves exceptionally high sulphuric acid concentrations and sulphur recovery rates.

KVT is an experienced, long-standing provider of environmental technologies. The company is a particularly well known as a supplier of turnkey off-gas treatment plants worldwide.

KVT's technologies use thermal and/or catalytic oxidation to convert sulphur-containing compounds in waste gases (H_2S, CS_2, COS or SO_2) into SO_3 and finally to sulphuric acid. While the recovery of concentrated sulphuric acid from waste gases or waste acid may be the main objective, KVT always ensures that emissions standards are complied with.

Fig. 2: **Sulfacid® process**



Source: NORAM

KVT's *OXYSULF* technology

OXYSULF, a new technology from KVT, is designed to reduce both investment costs and operating costs (*Sulphur* 383, p42). It represents a further development of the *SULFOX* technology originally introduced by KVT in the 1990s.

OXYSULF produces sulphuric acid from the desulphurisation of waste gases. It enables plant operators to eliminate sulphur emissions while at the same time boosting plant economics. The technology is being continuously improved and modified – in response to the changing requirements of KVT's customers and the demands of environmental regulators.

The experience gained by KVT in sulphuric acid plant design over three decades has led to many improvements being incorporated into the *OXYSULF* process, including:

- A new reactor design
- A new tail gas reactor concept
- A catalyst that delivers improved sulphuric acid concentration
- A higher sulphur separation rate with no waste stream (pure H_2SO_4 instead of gypsum)
- A controlled and safe emissions rate
- Improved reliability
- Better economics and sustainability.

OXYSULF's wide application range

The *OXYSULF* process can be applied in many different applications:

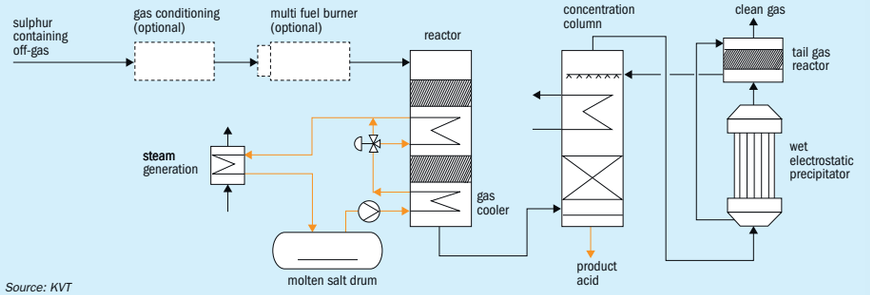
- Conventional sulphur-burning acid plants (S)
- Treatment of sour gas (H_2S)
- Metallurgical industry (SO_2 off-gas)
- Alkylation units in petroleum refineries (H_2SO_4 regeneration)
- Viscose fibre industry (H_2S, CS_2)
- Chemical industry, coal gasification, natural gas processing and refinery acid gas treatment (H_2S, CS_2, COS).

Due to the wide range of applications, KVT has defined four types of *OXYSULF* process. These offer each industry a specific solution:

- *OXY NK* for lean H_2S, CS_2 (e.g. viscose off-gas) and lean SO_2 (e.g. furnace flue gas)
- *OXY HK* for rich H_2S (e.g. refineries, high heat release favours steam generation)
- *OXY MET* for 'dirty' SO_2 (e.g. metallurgical, gas cleaning necessary)
- *OXY SAR* for spent acid and sulphate regeneration (e.g. various petrochemical industries).

KVT has delivered two *OXYSULF* references to date, one in the metallurgical industry and one in the viscose industry.

Fig. 3: **OXYSULF sulphuric acid process for desulphurisation of waste gases**



Source: KVT

The *OXYSULF* process

The *OXYSULF* process is shown in Figure 3. The off-gas gas is firstly pre-treated by passing through a gas conditioning system. This can employ a pre-filter, a scrubber, a Dry-Fil hot gas filter or a preheater, depending on the application. Pre-treatment is followed by catalytic oxidation alone, or by a combination of thermal and catalytic oxidation, according to the concentration of sulphur compounds present. In both cases, the gas is passed over a multi-bed catalyst reactor and then passed onwards to a concentration column and a final tail-gas treatment stage.

Catalytic oxidation is an exothermic process which takes place at temperatures between 200-500°C. The raw gas is initially pre-heated to achieve the maximum conversion rate of SO_2 into H_2SO_4 via a series of exothermic reactions. The energy from these reactions can be captured efficiently by a heat recovery system and used for lucrative steam production.

Gas emerging from the concentration column still contains sulphuric acid aerosols. These are removed (to <5 mg/Nm^3) by a wet electrostatic precipitator (WESP). Precipitated acid is collected in the sump of the WESP and routed to the top of the concentration column to be recovered as highly concentrated acid. Adding a tail-gas reactor can achieve a H_2SO_4 concentration of 98 percent and a sulphur recovery rate of 99.9 percent. A tail-gas reactor also ensures the lowest possible SO_2 emissions in the clean gas (<50 mg/Nm^3).

OXYSULF – key advantages

KVT's *OXYSULF* design improves plant reliability by including a special reactor sump lining and glass tube heat exchangers, as these items are typically prone to corrosion.

OXYSULF's novel design also incorporates new materials and alternative technologies such as the molten salt heat exchanging system. This enables the plant to be operated at high temperatures and pressures.

OXYSULF delivers excellent energy recoveries and sulphur yields. The technology is flexible too, being able to handle various gases and hydrocarbons, and is also well suited to refurbishment or expansion projects.

The concentration column is the core element of the entire *OXYSULF* process. Leakages and inefficient cooling are avoided, thanks to its improved design, and the highest availability can also be ensured.

Exceptionally long lifetime and operation flexibility is guaranteed due to the use of the highest quality vanadium catalysts and KVT's specially designed platinum catalyst.

Being a zero waste process, there are no costs for waste management either. The only plant outputs are concentrated sulphuric acid, steam and cleaned gas. The lowest emissions limits can also be met without the need for consumables, thanks to the WESP and the tail-gas reactor.

Sulphuric acid tower design

Sulphuric acid towers are instrumental for the successful operation of sulphuric acid plants (sulphur-burning, metallurgical and acid regeneration types) as well as some gas-cleaning and SO_2 plants. The design of sulphuric acid towers requires an understanding of:

- Mass transfer
- Hydraulics
- Packing performance

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Table 1: **Variation in acid tower diameter/volume vs plant size for two different packing types: standard three-inch saddles and *Flexeramic 88***

Size of the plant (t/d)	3 inch standard saddles (diameter/volume)	Flexeramic®-88 (diameter/volume)
500	3.4 m / 30 m³	2.8 m / 20 m³
1,000	4.7m / 50 m³	4.0 m / 40 m³
2,000	6.7 m / 110 m³	5.7 m / 80 m³
3,000	8.2 m / 160 m³	7.0 m / 110 m³
4,000	9.5 m / 210 m³	8.1 m / 150 m³
5,000	10.6 m / 260 m³	9.0 m / 190 m³

Source: Koch Knight

- Mist formation and removal
- Mechanical design
- Bricking design
- Corrosion
- Materials engineering
- Practical engineering and experience.

Sulphuric acid towers have traditionally been constructed of robust brick-lined steel, providing worry-free operation over a wide range of acid temperatures and acid concentrations, as well as excellent longevity, typically lasting 30+ years. Alloy metal towers have also become popular in recent times

Both bricked and alloy towers have their own distinct benefits and limitations. Alloy towers are lighter and have a quicker installation time, for example, factors that are often critical in plant retrofits. But they also require tighter acid concentration control than brick-lined towers. The latter are capable of withstanding a wider range of acid concentrations should a process upset occur.

NORAM Engineering has capabilities in the design, construction and installation of sulphuric acid towers of all sizes, for multiple applications, and supplies both brick-lined steel and alloy towers (*Sulphur* 382, p32). Both types can be designed to provide many decades of reliable and trouble-free operation. NORAM's brick-lined towers include state-of-the-art bricking, with innovative stable dished bottoms, self-supporting dome packing support, and internal or external water dilution.

The mechanical design limit for NORAM brick-lined towers is 10 metres diameter, which is typical for a 5,000 t/d capacity acid tower. Towers are limited to this diameter by the dome's mechanical strength. To stay within that diameter limit, larger capacity plants with brick-lined towers either require a different type of packing support, or need two towers operating in parallel. Alternatively, a larger diameter alloy tower could be implemented.

NORAM's alloy towers are fabricated in high-silicon stainless steel (*NORAM SX*™, UNS 23615). There are no mechanical limits to the diameter of the towers made of *NORAM SX* using a metallic support grid made of the same material. This type of tower can be designed for plants larger than 5,000 t/d with diameters in excess of 10 metres.

Optimising acid tower design

The diameter of an acid tower depends on factors such as:

- Gas flow
- Liquid flow
- Packing type
- Target pressure drop
- Need for the tower to fit the existing footprint
- Potential for future expansion.

Acid towers require packing to achieve intimate contact between gas and liquid. The required packing height depends on the mass transfer rate and the absorption efficiency required.

Koch Knight report that, compared to the previous generation, some newer sulphuric acid plants with wider diameter towers have experienced an increase in failures. The coefficient of thermal expansion plays a greater role in these larger diameter towers, affecting their reliability – this applies to to both brick-lined and alloy towers. (*Sulphur* 382 p32).

Acid brick lining systems may provide pathways which acid can flow along due to partial porosity, imperfections or via mortar joints. These potential pathways can be sealed by protecting the steel shell with a membrane prior to installing the acid brick lining.

In the past, the preferred membrane material was a trowelled-on acid-resistant mastic. This performed well on smaller towers, lasting for years with little or no maintenance. The major issue with trowelled-on mastic, however, is that it solidifies over time or when it comes into contact with sulphuric acid. Once solidified, and under the stress and compression of brick/shell movement, the mastic will eventually crack or abrade due to its lack of elasticity. In addition, the thickness of the mastic is difficult to control – which can result in a thinner membrane than desired.

Koch Knight's *Pyroflex*® acid resistant sheet lining is an alternative membrane option which meets the need for a corrosion barrier and offers a mechanical means of managing gaps between the acid brick lining and the steel shell.

Pyroflex® sheet lining has several valuable properties. Its insulation properties lower the shell temperature while increasing the brick lining temperature. The thermal expansion of the *Pyroflex*® and its compressibility also increases stress in the lining. Because of this, the sheet lining pushes the brick lining away from the shell, as *Pyroflex*® shows some ductility at tower operating temperatures.

Reducing tower size through packing selection

Reducing the diameter of sulphuric acid towers is desirable as it has two benefits: It reduces both capital cost while also improving the performance and reliability of the lining system.

The diameter of acid towers can be reduced, for a given plant capacity, by replacing random packing with structured packing. In a new plant, savings of up to 15 percent of the total tower cost can potentially be achieved, for example, by replacing standard three-inch (75 mm) saddle with structured packing, as this enables a significant reduction in tower diameter for the same plant size. This is illustrated by Table 1 which shows the reduction in tower diameter possible when substituting standard saddle with Koch Knight's *Flexeramic*® *88* structured ceramic packing.

In summary, when debottlenecking larger plants, Koch Knight recommends designing these with standard saddles in mind for packing, while using *Pyroflex*® acid resistant sheet lining to avoid additional stresses. Alternatively, the diameter of the plant's acid tower – and the power consumption of the blower – can be reduced by adopting structured packing such as *Flexeramic*® *88*. Either option is advantageous for sulphuric acid towers, in terms of both cost and performance. ■

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The Umm Wu'al phosphoric acid plants – a success story

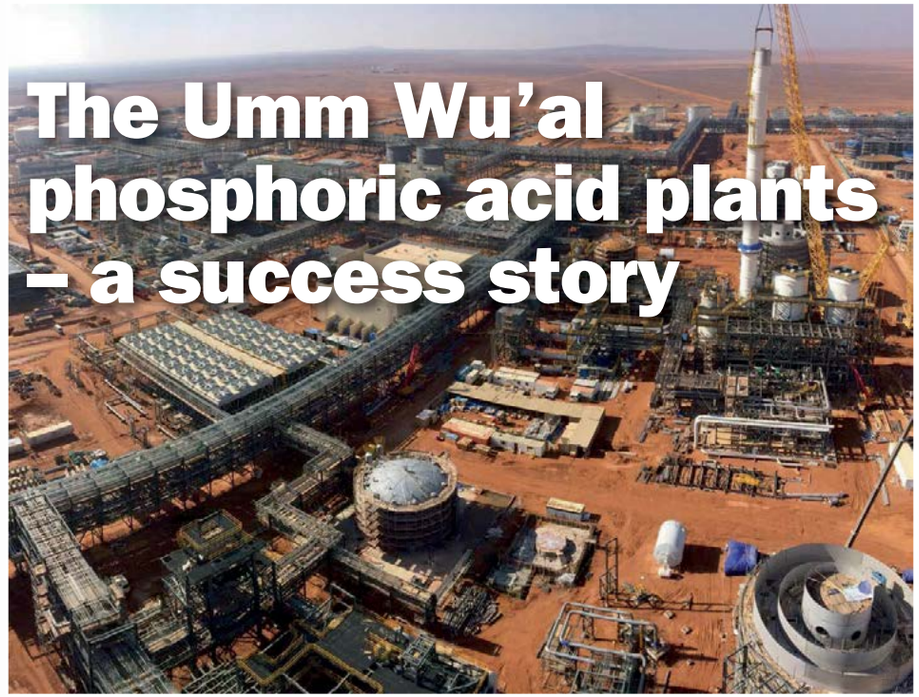

PHOTO: LONGXIN CONSTRUCTION GROUP

Three large-scale phosphoric acid plants constructed as part of the world-class Umm Wu'al project in Saudi Arabia are now fully operational. **James Byrd** of Worley (formerly Jacobs ECR) describes the execution of the project from basic engineering through to plant performance tests.

Umm Wu'al phosphoric acid plants.

Three phosphoric acid plants were constructed as a part of the Umm Wu'al chemical complex in Saudi Arabia. Ma'aden and Mosaic joined together to spearhead the project's management and develop what is now a world-class phosphate operation.

Jacobs ECR, now Worley, was selected to provide the technology for the phosphoric acid plants and perform basic engineering. Hanwha was awarded the engineering, procurement and construction (EPC) contract to build the plants. As a part of the overall project strategy, Hanwha was managed by a joint team from Ma'aden and Mosaic with Jacobs providing detail engineering support.

The outcome of this highly collaborative project execution model was the delivery of three of the best operating phosphoric plants in the world. All three plants successfully met all their specified performance parameters shortly after start-up.

This article outlines how this was achieved and describes project execution from basic engineering through construction, culminating with the process performance test results.

Introduction

Umm Wu'al, Ma'aden's second large-scale phosphate project, is located in the Turaif area of northern Saudi Arabia. The large complex contains several world-scale plants. The focus of this article is the three phosphoric acid plants residing within this complex.

Umm Wu'al was developed by the Ma'aden Wa'ad Al Shamal Phosphate Company (MWSPC), a joint venture between three partners, Ma'aden, Mosaic, and Sabic, each with an interest of 60 percent, 25 percent and 15 percent, respectively.

In a departure from its previous large-scale phosphate project in Saudi Arabia, Ma'aden decided to compare phosphoric acid technologies rather than simply select the hemi-hydrate (HH) process chosen previously. Ma'aden eventually selected the di-hydrate (DH) process as the technology

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for Umm Wu'al, after taking into account their previous experience with HH and all of the other factors reflecting the particular circumstances of the latest project.

Jacobs ECR, now Worley, was selected as the licensor for the phosphoric acid plants (PAP). Worley's subsequent purchase of Jacobs ECR in April 2019 included the licensing technology for phosphoric acid. The licensing team remains intact and is still located in Lakeland, Florida, in the United States. Worley will therefore be named as the licensor throughout the remainder of this article

The licensor team worked closely with the project team throughout the engineering and construction phases. The end result was the delivery to MWSPC of some of the best operating phosphoric acid plants in the world. Since their start-up in 2017 (*Fertilizer International* 483, p44), the plants have been resilient and consistent in producing acid at or above design parameters. The factors that made this project successful are described below. The process performance guarantee results are also shared.

Keys to success

For any project, it is critical that the right design decisions are made earlier rather than later – given that early decisions will have a greater influence on the project's direction and eventual outcome.

Worley was able to maintain the same core team throughout the entire life cycle of this PAP project. This provided consistent direction in what was a schedule-driven project. And that direction was communicated to, and agreed by, project management throughout all phases of the project. In fact, the support Worley received from the project team for all matters involving process performance guarantees – of which there were many – was a key noteworthy point. That is not to say the client had no input into the project. It simply recognises that the client consistently listened and then acted appropriately whenever process guarantees were a consideration.

It was not just the licensor's core team that competed the project intact. Valuably, the project management team also remained in place throughout the project. This familiarity between all team members, spanning several companies, helped foster an approach where everyone was working collectively towards a high quality product and outcome.

The project team, despite being split across multiple companies, also had a well-defined structure with clear roles and responsibilities providing consistent direction. It cannot be emphasised enough that the presence of a strong team ethic, shared by all participants, was key to the successful execution of this project.

Project Scope

As is typical in a large-scale world-class project, the project phases were segregated into the:

- Process design package (PDP)
- Basic engineering
- Detail engineering
- Construction
- Commissioning
- Start-up concluding with performance testing.

Worley was selected to provide the process design package and perform basic engineering. The licensing team for phosphoric acid is located in Lakeland, Florida. However, because the Umm Wu'al project included many other world-class plants and the Lakeland office is a technology centre, the entire basic engineering package was in fact managed from Jacobs' Reading office in the UK.

> **"It cannot be emphasised enough that the presence of a strong team ethic was the key to the project's successful execution.**

Because of the project's schedule-driven nature, pilot plant testing was done concurrently with the PDP and finalised during basic engineering. A conservative approach to design was therefore adopted, pending the availability of test results. Then, towards the end of basic engineering, the pilot plant results were used to confirm the design parameters to ensure the process guarantees.

Design basis

The design basis for the Umm Wu'al project was the production of 1.5 million tonnes of P_2O_5 annually off site. The design had to be robust enough to take into account:

- The remote desert environment
- Limited support services for the location
- Reliability in design – as parts can take time to procure in remote regions
- A transient multi-lingual workforce
- Ease and flexibility of operation.

Early in engineering it was decided that the three trains would have nameplate capacities of 1,615 t/d each. This would allow for catch-up in production if unanticipated downtime occurred, such as power outages or other influences outside of the control of the plant.

All weak acid was to be converted to merchant-grade acid (MGA). This was primarily dictated by the transportation requirements, as all acid needed to be moved by rail to Ras Al Khair, approximately 1,200 kilometres away. The plants were also designed to be zero-discharge units with an integrated design to take advantage of higher asset utilisation. Product-quality fluorosilicic acid (FSA) was specified, and wet gypsum stacking was also designed into the PAP.

The Worley reactor was designed specifically for the source ore and the production rate. Integral to this was a one flash cooler design for each reactor, with a precondenser for heating filter wash water and a silica removal system in the vapour ducts. Two tilting pan filters were each designed at 70 percent of the total rate to take advantage of additional production during weekly washes. This also provided a means of handling fluctuations in the concentrate feed, and provided an extra layer of reliability should one filter go down unexpectedly.

Because of the arid location and its scarce water sources, the water balance was a critical plant design parameter. Heat loads also had to be accounted for by utilising non-contact cooling towers. This was done to prevent the cooling towers from becoming point sources for fluorine emissions and to protect the water from scaling ions.

Consequently, the water balance at Umm Wu'al is unique and multi-faceted. It includes a dedicated vacuum pump cooling water loop and a means of recovering P_2O_5 in wash waters and spills. Furthermore, ion segregation was a primary driver in water handling so as to minimise scaling of critical equipment. The water balance also needed to account for other miscellaneous water inputs.

Cross flow scrubbers for the systems were designed specifically to include all ancillary tanks and products. These were integrated into the FSA recovery system, enabling the facility to comply with the World Bank's fluorine emissions standards for phosphate plants.

Table 1: **Selected process parameters for the three Umm Wu'al phosphoric acid plants versus the project's performance guarantees**

	Unit	Performance guarantee	A train actual	B train actual	C train actual
P_2O_5 production rate ex filter (1,615 mt/day/train)	t/d P_2O_5	≥1,615	1,621	1,665	1,628
P_2O_5 production rate ex concentrate plant	t/d P_2O_5	≥1,615	1,696	1,673	1,712
Reactor and filter P_2O_5 recovery	% P_2O_5	≥95	96.26	96.45	96.31
Evaporator P_2O_5 recovery	% P_2O_5	≥99.7	99.99	99.98	99.99
P_2O_5 content of acid ex filter (28% of P_2O_5)	% P_2O_5	27-28	27.2	27.2	27.5
P_2O_5 content of acid ex concentration plant (54% of P_2O_5)	% P_2O_5	≥54	54.9	55	54.5
FSA quality – P_2O_5	% P_2O_5	≤0.1	0.07	0.08	0.06
FSA quality – H_2SiF_6	% H_2SiF_6	≥22	24	23.2	23.2

Source: Worley

Project management

Ma'aden oversaw all plants and technologies with the assistance of Mosaic's technical expertise. The technical team from Mosaic linked-up with Worley's technical team to make joint design decisions for the betterment of the project. This collaboration, which began during basic engineering, was a strategic one and the resulting team synergy continued throughout the rest of the project.

Project packages were awarded to several bidders at the end of basic engineering. Worley and Mosaic both vetted the bidders from a technical perspective as part of a formal process managed by Ma'aden. This process revealed which bidders were the best fit moving forward.

Hanwha was selected as the lump sum EPC contractor. The South Korean company delivered the project's detail engineering from their offices in Seoul. As part of the award, Ma'aden required Hanwha to employ Worley to oversee critical technical aspects throughout the rest of project execution. The project team located in Seoul was comprised of staff from Hanwha, Mosaic and Ma'aden. It did not take long for Hanwha to integrate to form a well-functioning team with the already stable Mosaic, Worley and Ma'aden team members.

Hanwha is a capable and world-renowned EPC contractor. Indeed, by integrating the technical assistance offered from both Worley and Mosaic, Hanwha was able to perform detail engineering to a high level, despite this being the company's first phosphate project.

All project decisions followed a team-based decision-making process designed to ensure the best outcome occurred. Although the Ma'aden and Mosaic team ultimately made all decisions, they backed the licensor's position where process guarantees were concerned.

Construction

Hanwha was responsible for on-site construction in Saudi Arabia. Mosaic constructed a camp at the remote desert site so it could be resident during construction oversight. The project's commissioning teams were supported by both Mosaic and Worley. Teams from both companies also supported the project's start-up.

A perfect start-up has likely never occurred in a phosphoric acid plant. But this one certainly came close! Generally, only minor issues were identified and needed to be resolved during the start-up phase. The feed from the beneficiation plant was variable and of lower quality than the design basis, for example, but the robust design of the PAP ensured production rates were still met shortly after start-up. In fact, full rates were achieved within one week of each of the three production trains starting up.

Because of the integrated design, the performance tests were independently conducted on the front end and back end of the plants. These were conducted shortly after start-up.

For all three operational phosphoric acid plants (trains A, B and C), process parameters surpassed all of the numerous process performance guarantees. Some select parameters are shown in Table 1.

Conclusions

There has never been a plant built where lessons cannot be learned and then applied to the next plant. Even with the successes of the Umm Wu'al project, as described here, there are undoubtedly some salutary lessons that can be applied subsequently.

The robustness that was designed for, and then built-in, made the three phosphoric acid plants resilient enough to withstand and deal with a lower-than-specified rock concentrate. The plants also experienced some minor mechanical issues.

The success of the Umm Wu'al project was, however, ultimately judged by the performance of the plants after start-up. On that basis, judged by the exceedance of performance guarantees (Table 1), the plants are running well and have been doing so since start-up.

While no project is without its challenges, the Umm Wu'al plants have exceeded expectations. Indeed, favourable comments about their robust design and their ability to handle variable feeds – one of the primary challenges for a PAP operator – are still filtering back from those on site.

The factors behind the success of the Umm Wu'al project were many. But without the teamwork that occurred between many companies – from Lakeland to Casablanca to Reading to Seoul to Mumbai to Turaif – this project would not have been so well executed and delivered so successfully. ■

PROJECT PROFILE PK

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North America's phosphate producers

We profile the US 'big three' North American phosphate producers, Mosaic, Nutrien and Simplot, and disruptive market entrant Itafos.

For decades during the post-war period, North America enjoyed a commanding position globally as a supplier of phosphate rock and finished phosphate products. But since the 1990s the region's global influence has been increasingly challenged by the rise of other centres of phosphate production – in China, Morocco, India, Saudi Arabia, Russia, Brazil and elsewhere.

Having once been a major phosphate import market, China, in particular, has transformed itself through a crash programme of industrialisation into the world's largest producer of finished phosphates and a major phosphate exporter.

Although now eclipsed by China's phosphate fertilizer (DAP/MAP/TSP) production might – a mammoth 37.2 million t/a of capacity – the US still ranks as the second largest global production centre (Figure 1) with a greater finished phosphates capacity (13.9 million t/a) than its nearest rival Morocco (11.4 million t/a).

North America itself also provides an attractive, large, mature and sophisticated agricultural market for its domestic phosphate fertilizer producers. Apparent consumption of phosphate fertilizers (DAP/MAP/TSP) in North America last year was an estimated 9.4 million tonnes – about 13 percent of total world consumption.

While total global phosphate consumption – for phosphoric acid, fertilizer and other products – is projected to grow from 47 million tonnes P_2O_5 in 2019 to 50 million tonnes P_2O_5 by 2023, US annual consumption is expected to remain stable at between 4.0-4.5 million tonnes P_2O_5 over the medium-term.

Production overview

In the US, phosphate rock is mined by five companies from 10 mines in four states. This ore is beneficiated into 23.0 million tonnes of phosphate rock concentrate with a market value of around $1.6 billion. Florida and North Carolina combined account for more than 75 percent of total US output, with Idaho and Utah responsible for the remainder.

Canadian phosphate rock mining was never on the same scale as in the United States. Agrium, now part or Nutrien, closed Canada's last operational phosphate rock mine in Kapuskasing, Ontario, in 2013 after its reserves were exhausted. Agrium/Nutrien subsequently supplied its Redwater, Alberta, phosphate fertilizer plant with imported Moroccan phosphate rock instead, until its recent closure. US phosphate rock production peaked at 54.4 million tonnes in 1980, accounting for 37 percent of world production that year. Production has slid inexorably since then to 23.0 million tonnes in 2019, around 10 percent of global production. That figure is less than one-quarter of China's 110 million tonne phosphate rock production volume, and is also eclipsed by the 36 million tonnes produced by Morocco in 2019.

US phosphate reserves are estimated at one billion tonnes currently, sufficient for a further 30-40 years of mining at current extraction rates. In Florida, abundant unexploited reserves still exist south of the state's historic mining area, centred on Polk, Manatee and Hillsborough Counties. The Mosaic Company was recently granted a permit for its Ona phosphate mine project in Hardee County, securing an additional 160 million tons of phosphate rock for future mining.

As domestic production has declined, the US has become a significant import destination for phosphate rock in recent years. Imports ranged from 1.6-2.8 million t/a between 2015-2019, with Peru (79%) and Morocco (20%) acting as the main suppliers during this period.

More than 95 percent of the phosphate rock mined in the United States is consumed in the production of phosphoric acid, an intermediate in the manufacture of phosphate fertilizers, both granular and liquid, and feed phosphates. About 50 percent of the wet-process phosphoric acid produced is subsequently exported in the form of diammonium (DAP) and monoammonium phosphate (MAP) and merchant-grade acid (MGA).

Despite no longer occupying the pre-eminent market position it once held, North America nevertheless remains a significant global player. North American phosphoric production, at its peak of 12 million t/a in the late 1990s, once accounted for almost 45 percent of world production. The region's phos acid output has fallen back to below eight million t/a since then, accompanied by a drastic decline in world market share to around 15 percent (Figure 2, left).

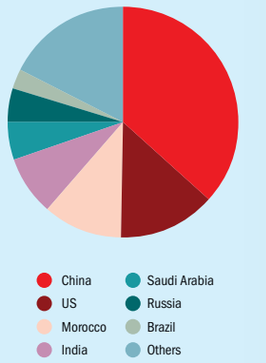
North American phosphate product exports (DAP/MAP/TSP) have followed a similar trend. International deliveries once had a two-thirds share of the global export market, peaking at 12 million t/a in the late 1990s. Exports have steadily fallen during the intervening two decades, however, to around 3-4 million t/a currently, with a corresponding decline in world market share (Figure 2, right).

Domestic consolidation, international expansion

The North American phosphates industry has regularly been convulsed by a sequence of mergers and closures stretching back three decades (Figure 3). This has seen the industry consolidate from 18 companies operating 22 production sites in 1990 to just four companies operating from 10 production sites currently (Figure 4).

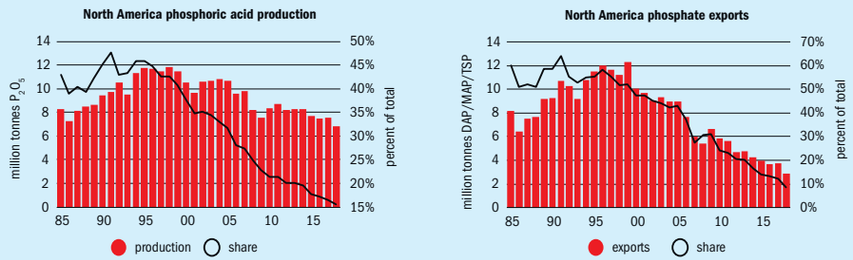
Yet the North American phosphate industry has shown remarkable resilience in response to a seemingly inexorable process of domestic closure and consolidation. Indeed, the industry has managed to maintain and arguably grow its global presence, securing access and logistical proximity to new markets by acquiring or helping to develop lower-cost international production assets.

Fig. 1: **2019 global phosphate production capacity (DAP/MAP/TSP) by country**



Source: IFA

Fig. 2: **North American phosphoric acid production (left) and phosphate exports (right): volumes and global market share, 1985-2018**



Source: Mosaic

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Fig. 3: **Phosphate industry consolidation in North America, 1990-2019**

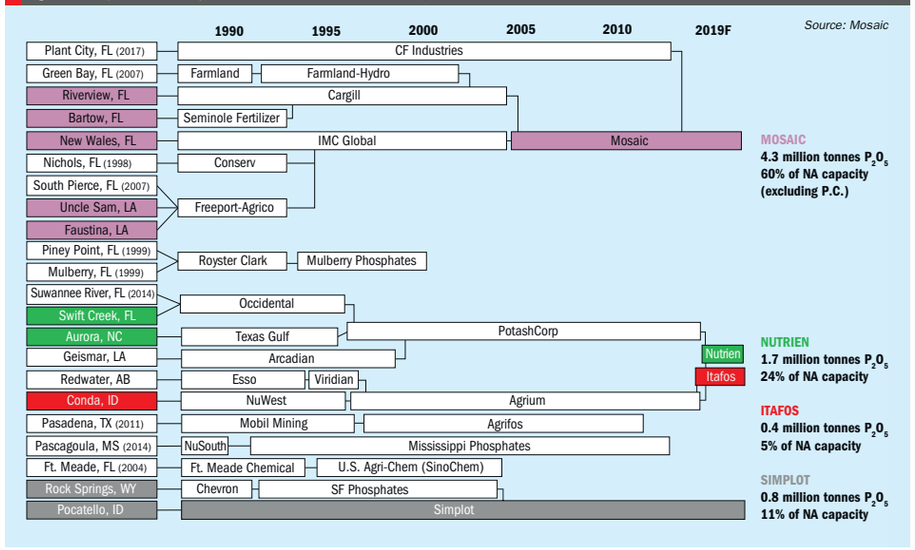

Fig. 4: **North American phosphate plants**

Mosaic

The Mosaic Company, originally formed by the merger of Cargill's crop nutrition division and IMC Global in 2004, is the largest phosphate producer in North America, with a 60 percent share of regional capacity (Figure 3) Mosaic sold 8.2 million tonnes of finished phosphates in 2019. These sales included 3.2 million tonnes of its *MicroEssentials* speciality product.

Mosaic extracts phosphate rock at four mines in Florida: South Fort Meade, South Pasture, Wingate and Four Corners. These collectively produced 12.2 million tonnes of phosphate rock in 2019, down two million tonnes on 2018, due to the continued idling of the South Pasture mine. Mosaic also operates three downstream phosphate production sites in Florida, namely New Wales – the largest phosphate production complex in North America – as well as production plants at Riverview and Bartow (Figure 4).

Mosaic also owns and operates two phosphate production plants at Uncle Sam and St James (Faustina) in Louisiana (Figure 4). Both plants – inherited from Freeport-Agrico via the IMC Global merger (Figure 3) – are supplied with phosphate rock from Mosaic's Miski Mayo joint venture mine in Bayovar, Peru. Mosaic temporarily idled its Louisiana operations for part of 2019 in response to market conditions, reducing its annual phosphate plant operating rate to 83 percent.

In a major strategic decision, Mosaic closed its Plant City production site in Hillsborough County, Florida, last year – one of its highest cost plants – after a prolonged period of idling. The decision has removed around 1.3 million t/a of domestic production capacity from the US phosphate market.

Nutrien

Saskatoon-headquartered Nutrien, the world's largest crop nutrient company, was formed from the merger of Agrium and PotashCorp in 2017. The Canadian fertilizer giant is the second largest phosphate fertilizer producer in North America. Its phosphates production capability of 1.7 million tonnes P_2O_5 is equivalent to 24 percent of regional capacity (Figure 3).

Nutrien's two main US production plants in Florida and North Carolina (Figure 4) have the capacity to produce around five million tonnes of phosphate fertilizers annually – with 3.4 million tonnes dedicated to liquid products and 1.6 million tonnes to solid products. Nutrien also has additional annual capacity of 0.7 million tonnes and 0.3 million tonnes for feed phosphate and purified phosphoric acid, respectively, from four smaller-scale US manufacturing sites.

The company manufactured and sold 2.9 million tonnes of finished phosphate products in 2019 – down 12 percent on 2018 due to adverse weather affecting North American spring and fall application seasons. This production volume included 2.1 million tonnes of phosphate fertilizers and 0.8 million tonnes of phosphate destined for the feed and industrial market. These phosphate tonnages compare with Nutrien's massive product sales of 11.5 million tonnes for potash and 10.3 million nitrogen tonnes in 2019.

Nutrien used the 2017 merger as an opportunity to rationalise its phosphate operations and eliminate any reliance on higher cost phosphate rock imports. This included the decision to end phosphate production at Agrium's Redwater plant in Alberta. This non-integrated plant, which was reliant on imported phosphate rock supplied by Morocco's OCP, was reconfigured to produce ammonium sulphate instead – part of a $200 million investment in high-return brownfield projects. Nutrien also closed its smaller Geismar, Louisiana, phosphate plant inherited from PotashCorp at the end of 2018 – another site reliant on imported phosphate rock.

These closure decisions have allowed Nutrien to concentrate on increasing production at its two remaining integrated phosphate plants in Aurora, North Carolina, and White Springs, Florida (Figure 4). Both plants have their own dedicated phosphate rock mines. Nutrien also operates three phosphate feed plants in Marseilles, Illinois, Joplin, Missouri and Weeping Water, Nebraska, together with an industrial phosphoric acid plant in Harrison, Ohio.

The Aurora phosphate plant has the capacity to produce 2.7 million tonnes of liquid and 0.8 million tonnes of solid fertilizer products annually. Nutrien's smaller White Springs plant has the capacity to produce 0.8 million tonnes of solid products and 0.7 million tonnes of liquid products per year. The company restarted the second solid phosphate production line at White Springs at the end of 2018 and began supplying the

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Western Canadian market with US-produced solid phosphate.

JR Simplot

JR Simplot is an international food and agricultural conglomerate headquartered in Boise, Idaho. The company's founder Jack R Simplot famously supplied potatoes to MacDonald's before diversifying and expanding the privately-held business, eventually moving into mining and phosphate fertilizer production.

Simplot's integrated business portfolio covers phosphate mining, fertilizer manufacturing, farming, ranching, food processing, food brands, and other agricultural interests. With more than 11,000 employees worldwide, the company's global operations distribute products to more than 60 countries.

Simplot is the third-largest phosphate producer in North America with a production capability of around 800,000 tonnes P_2O_5, equivalent to around 11 percent of total regional phosphate operating capacity. Uniquely, the company is the sole phosphate producer to have emerged unscathed from two decades of industry consolidation (Figure 3).

Simplot operates two phosphate mines at Smoky Canyon, Wyoming, and Vernal, Utah. These supply downstream processing and production sites at Pocatello, Idaho and Rock Springs, Wyoming, respectively, via slurry pipelines (Figure 4).

The Don plant at Pocatello, Idaho was built in 1944 and produces over one million tons of dry and liquid phosphate fertilizers, feed phosphates and purified phosphoric acid. Annually, the plant consumes 1.6-1.8 million tons of phosphate rock – 100 percent of the ore mined at Smoky Canyon – 400,000 tons of sulphur and 90,000 tons of ammonia. The 27-mile section of slurry pipeline linking Smoky Canyon phosphate mine with Conda, near Soda Springs, Idaho, opened in 1984. This was followed in 1991 by the opening of a second 60-mile section to connect Conda with the company's Don fertilizer plant.

Simplot's Vernal, Utah mine was originally developed by the San Francisco Chemical Company in 1960. It was later purchased by Chevron in 1981 who began building the Rock Springs fertilizer manufacturing plant in Wyoming in 1984 and constructing a 96-mile underground slurry pipeline to transport phosphate rock from the Vernal mine. The Rock Springs plant and slurry pipeline subsequently entered operation in 1986. Simplot part-purchased the mine, pipeline and fertilizer plant in a joint venture with Farmland Industries in 1992 – before purchasing these assets outright in 2003.

Rock Springs manufactures phosphoric acid (54%), super phosphoric acid, (SPA) granular monoammonium phosphate (MAP), and fluorosilicic acid (FSA). Simplot expanded the dry phosphates production capacity of Rock Springs by 30 percent between 2012 and 2014.

Itafos

Itafos is North America's fourth phosphate producer and its newest market entrant. The Canadian company is the smallest of the North American producers, owning and operating a single production plant and dedicated phosphate mine at Conda, Idaho (Figure 4). It possesses five percent of North American phosphate capacity with an annual production capability of around 400,000 tonnes P_2O_5 (Figure 3).

Itafos was founded in Toronto in 2008 as the MBAC Fertilizer Company before changing its name in 2017. It originally developed the vertically-integrated Arraias single superphosphate (SSP) project in Brazil, before buying into the North American market. Itafos successfully acquired Agrium's Conda, Idaho, phosphate mine and plant in 2017. These assets were divested by Agrium immediately prior to its merger with PotashCorp.

Conda has an annual production capacity of around 550,000 tonnes and manufactures MAP, SPA and merchant grade phosphoric acid (MGA). It is one of only three SPA producers in the US. Itafos has a long-term MAP offtake agreement for the Conda plant together with an ammonia supply contract that is linked to fertilizer prices. Conda's dedicated phosphate mine has sufficient permitted reserves to operate until the end of 2024. Itafos plans to continue to supply Conda beyond this date by developing a new one million t/a capacity phosphate mine at Paris Hills, Idaho.

Going global

North American phosphate producers – faced by consolidation in their domestic market and shrinking global market share – have generally grown their businesses though international expansion. Simplot and Nutrien, for example, have long-established international operations and distribution networks – although these do not have a specific phosphates market focus. Instead, concerted efforts by Mosaic to develop an international production footprint have been one the most notable developments during the past ten years.

Indeed, Mosaic has every right to call itself the only truly global phosphate producer. In 2018, the Florida-headquartered company secured a significant presence in Brazil – a global agricultural powerhouse and a fast-growing, large volume phosphate market – via its acquisition of Vale Fertilizantes. Its newly-formed Brazilian subsidiary Mosaic Fertilizantes currently operates five phosphate mines and four downstream phosphate production plants in Brazil.

Mosaic has also secured access to Asian markets through its 25 percent stake in the Ma'aden Wa'ad al Shamal Phosphate Company (MWSPC) in Saudi Arabia, a joint venture with the Saudi Arabian Mining Company, Ma'aden (60 per cent) and Saudi Basic Industries Corporation (SABIC, 15 per cent). MWSPC owns a large-scale phosphate mining complex and phosphoric acid plants at Wa'ad Al-Shamal in northwest Saudi Arabia and a three million tonne capacity diammonium phosphate (DAP) plant at Ras al Khair on Saudi Arabia's gulf coast.

Finally, Mosaic has a controlling majority stake (75%) in Miski Mayo, a joint venture phosphate mine in Bayovar, Peru. The 3.5-4.0 million tonnes of phosphate rock mined by Miski Mayo guarantees Mosaic a secure supply for its Louisiana phosphate operations. Bayovar mine also supplied Mosaic Fertilizantes in 2019 during the temporary temporarily idling of two of its mines.

Itafos also has an international production footprint. As well as supplying the Brazilian market via its recently recommissioned 500,000 t/a capacity Arrais SSP production plant at Tocantins, The company is also developing the 1.34 million t/a capacity Farim phosphate rock mining project in Guinea Bissau, West Africa. This had been expected to enter commercial production as early as the second-half of this year. Other Itafos projects under development include the Mantaro phosphate rock mining project in Peru and the Araxa and Santana phosphate projects in Brazil. ■

Evaporation and crystallisation technology

Evaporation and crystallisation are widely used throughout the fertilizer industry. Major applications and the types of equipment used are reviewed by **Laurent Palierne** and **Norbert Strieder** of GEA Group.

Fertilizer production relies on efficient processes and mature technologies. This article provides an overview of the use of evaporation and crystallisation technologies in fertilizer manufacture. The trend for purification to optimise product quality via precipitation, membrane filtration and ion exchange is also outlined.

There is increasing market demand for water-soluble value-added products for foliar applications, fertigation and NPK blends. For these end-uses, evaporation, stripping, crystallisation and membrane filtration units are a perfect fit for the production of high-purity solids with the right shape and size characteristics. These technologies can be harnessed to manufacture a long list of nitrogen, phosphate and potash products:

- Phosphoric acid
- Monoammonium phosphate (MAP)
- Diammonium phosphate (DAP)
- Urea phosphate
- Ammonium sulphate (AS)
- Ammonium chloride
- Ammonium nitrate
- Calcium nitrate
- Potassium chloride (MOP)
- Potassium sulphate (SOP)
- Magnesium sulphate
- Potassium phosphate
- Potassium nitrate (NOP).

By-products like calcium chloride are also produced in evaporation and granulation plants.

Technology basics

Evaporation and crystallisation are required in a production process whenever:

- Removal of water or another solvent is required
- Concentration has to be increased (product specification, chemistry, etc.)
- Volume has to be reduced (effluent, transportation, etc.)
- By-products or impurities need to be stripped or precipitated
- Valuable, high-purity crystals are being manufactured.

Equipment selection and plant design is influenced by many product- and process-specific factors. Customer requirements, notably site characteristics such as the energy source and its cost, play an equally important role in determining the process engineering design of an industrial plant – and minimising investment and operating costs.

Process scale-up and testing

Laboratory tests and trials in pilot plants are the prerequisite for determining the correct process engineering design. Once physical properties and behaviour are known, evaporation and crystallisation processes can then be modelled easily.

GEA's research and development laboratories have equipment that accurately represents most types of evaporators, crystallisers and membranes. These can be used to simulate the specific design envisioned for our clients and record relevant data.

These process designs can then be tested in small pilot plants to simulate specific process requirements. The samples produced are also suitable for further tests or market investigations. GEA's team can even perform the necessary tests or investigations at the client's own site, if products are too sensitive to be shipped to their facilities, or require special handling due to safety or health concerns.

Evaporator types

Several designs of evaporators (Figure 1) are available to satisfy a wide spectrum of process requirements. They include:

- Plate or tubular type falling film evaporators
- Plate or tubular type forced circulation evaporators
- Flash and multi-flash evaporators.

Different types of evaporator offer their own particular benefits. In each case, the most suitable type is selected by consideration of the main process parameters:

- Scaling tendency
- Product thermal sensitivity
- Required particle size
- Annual operating hours
- Accessibility for maintenance.

To ensure the longest operational lifetime, an evaporation plant is made of the most suitable and durable construction materials. These include carbon steel, stainless and duplex steel, high nickel alloys, nickel and titanium. Graphite, rubber-lined carbon-steel and fiberglass reinforced plastics are also selected for the most highly corrosive applications.

Types of crystallisation process and equipment

Crystallisation plants need to be engineered to meet the customer's product and process specifications (purity, particle size, operating time, etc.), while minimising investment and operating costs. The crystalliser unit is selected from a wide range of available technologies (forced circulation, draft tube baffled, Oslo or flash cooling) to match individual product requirements. Achievable particle size can ranges from microns to millimetres, depending on the crystalliser type (Figure 2).

Evaporative crystallisation is usually chosen as a process when the solubility of

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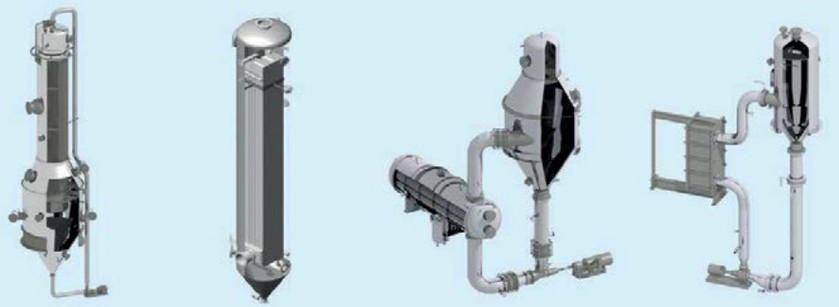
Fig. 1: **Evaporator types**



Tubular Falling Film Evaporator
- High heat transfer coefficient
- Low residence time
- Flexible operation
- Low temperature difference between shell and tube sides
- Separator can be monobloc type (as shown above or external type) High heat transfer coefficient

Plate Falling Film Evaporator
- Highest heat transfer coefficient and vapour/liquid separation
- Easily cleaned surface area up to 30,000m²
- Reduce thermal stress (no tubesheet)

Tubular Forced Circulation Evaporator
- Used when precipitation or severe fouling occurs
- Liquid is superheated in heat exchanger and evaporation occurs inside vapour separator
- Axial flow pump with flow up to 50,000 m³/h

Plate Forced Circulation Evaporator
- Suitable for low to medium evaporation capacity
- For liquid with only small amount of undissolved solids and with no fouling tendency
- Economical Plate and Gasket Heat exchanger

Source: GEA

Fig. 2: **Crystalliser types**

Forced Circulation Crystalliser
- Most popular type of crystalliser same principle as FC evaporator
- High evaporation rate
- Particle size <0.6 mm
- Internal or external circulation, with or without baffle zones and with no, partial or total classification.

Draft Tube Baffled Crystalliser
- No or little heat make-up (fine dissolution)
- Appropriate for vacuum cooling and moderate evaporation capacities
- Compact arrangement
- Particle size <2.5 mm
- Recirculation with agitator minimizes crystal breakage
- Fines can be dissolved

Oslo Crystalliser
- Desupersaturation of mother liquor through contact with biggest crystals from crystallisation chamber
- Crystals do not get in contact with stirring device, enables production of big crystals with narrow distribution
- Fines can be dissolved
- Particle size <6 mm
- Long production cycle between cleanings

Multistage Flash Cooling Crystalliser
- No heat exchange is required avoiding issues with encrustation: no cooling surface
- Particle size controlled by number of stages
- Low vacuum
- Reduced footprint

Source: GEA

the solute is virtually independent of temperature, thereby allowing supersaturation to be achieved by concentrating the slurry. This often requires a forced circulation system in order to control supersaturation, suspension density or crystal breakage.

Vacuum cooling crystallisation, in contrast, is usually chosen when the solubility of the substance to be crystallised is strongly temperature dependent. Supersaturation is generated by adiabatic cooling of the slurry by applying a vacuum, without a cooling surface and avoiding encrustation.

Where high quality standards are demanded, a recrystallisation stage can be added to improve the purity of the final product.

Heating configurations

Evaporation and crystallisation processes require a substantial amount of energy. The operating cost is directly linked to the type of evaporator and heating configuration selected (Figure 3):
- Single-effect
- Multiple-effect
- Thermal vapour recompression
- Mechanical vapour recompression
- A combination of those arrangements.

A new plant must balance energy costs with capital cost. This is generally achieved by finding the right compromise (total cost of ownership) between the customer's investment budget and operating cost, mainly linked to energy price levels. Existing production units can also be upgraded by reconfiguring and improving the existing heating configuration and/or by introducing more modern technology.

The main types of heating configuration are described below:
- **Multiple effect evaporator**: Classical multiple effect evaporation uses low-pressure steam for heating of the first effect and vapour for heating in the subsequent stage or stages. The number of stages employed reflects the relative importance of operating costs versus capital investment. These factors are linked to evaporation capacity and the boiling point elevation of the solution.
- **Thermal vapour recompression (TVR)**. TVR is used whenever steam is available at high- or medium-pressure. The flash energy of the steam is used to recompress part of the vapour given off, up to the pressure of the heating steam. This

Crystallisation theory

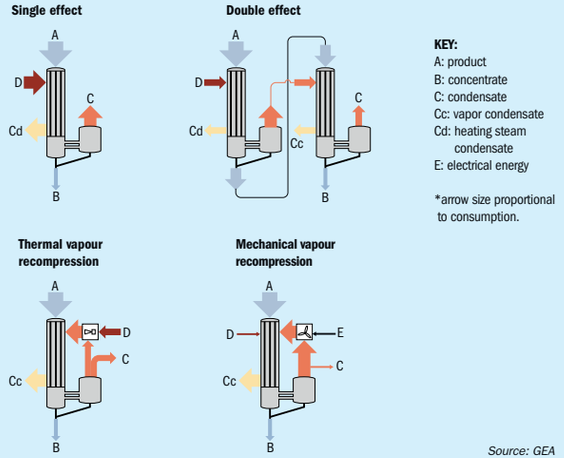
Millions of tonnes of fertilizer products are crystallised from solution at production plants worldwide every day. But how does this process work? In crystallisation, the objective is to recover a dissolved substance as a highly pure solid in the size and shape desired. Supersaturation – a temporary increase in solute concentration in the solvent above its equilibrium or solubility – is the driving force of crystallisation. It is mainly achieved by concentration, cooling or through chemical reaction.

The specific requirements of a crystalliser can vary widely, depending on the nature of the final product – such as purity, crystal size, final moisture – and its end-use. Sometimes the crystalliser's product is the solvent itself. In these cases crystallisation is used to separate-off the compounds that make the solvent impure.

One feature that is present in all crystallisation systems – regardless of the final use of the solvent or the crystalline solid – is the ability to separate crystals from a mother liquor. This ability is determined by, firstly, the crystal size and, secondly, by the type of separation equipment used. Centrifugation is by far the most efficient method of separation, provided the average crystal size is large enough.

The size of the crystals generated in a crystalliser is, in turn, dependent on their chemical and physical properties, as well as the characteristics of the solution in which they are dissolved in. At the same time, crystal size is also influenced by the type of crystallisation equipment and its method of operation. Selecting the correct type of crystalliser – operating within set physical and energy boundaries – can help improve crystal size by:
- Controlling the nucleation, attrition, and growth rate of crystals
- Destroying a fraction of the smaller crystals present within the crystalliser. ■

Fig. 3: **Mass/energy flow diagrams for an evaporator: four different types of heating configuration***



Source: GEA

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configuration, when available, achieves substantial savings in steam and cooling water at a relatively low cost.

- **Mechanical vapour recompression (MVR)**. In MVR, all of the process vapours given-off are recompressed to heat the evaporator. Virtually no steam is required, apart from pre-heating when starting the process. The only energy consumption necessary is the power required to drive the compressors. The compressors are usually driven by electrical power, although they can also be driven by a steam turbine. They are usually centrifugal fans, with one or several stages of compression, or positive-displacement type compressors. The current cost of energy makes MVR very attractive for evaporation and crystallisation, and choosing this option also delivers a saving on cooling tower and boiler investment. A scrubber can be installed prior to the fans for corrosive applications (e.g. acidic vapours).

Key applications

Evaporators and crystallisers are widely applied in the production of nitrogen, phosphate and potash fertilizers. They are used in the manufacture of commodity products like merchant-grade phosphoric acid (MGA) and muriate of potash (MOP, KCl) granules. More importantly nowadays, they are also used to manufacture value-added fertilizers, especially water-soluble products such as MAP, DAP, MKP, SOP and KNO_3.

GEA Group, with its expertise in evaporation and crystallisation, has developed and successfully installed numerous processes in fertilizer production plants worldwide. As well as operational industrial plants, the company's know-how includes process design expertise, gained from laboratory- and pilot-scale tests and process simulations carried out at GEA's development centre.

Potassium chloride (MOP) production

For brine sources, highly pure crystalline potassium chloride is recovered at multiple flash cooling crystallisation plants. Brines typically contains both sodium chloride (NaCl, sylvinite) and potassium chloride (KCl). This process is notable for:

- High efficiency heat recovery
- Temperature drop from 110°C to 45°C
- Heat recovery in four stages is usual with condensation in three re-cooling stages
- K_2O content adjustable between 58-62 percent by remixing condensate
- Crystal size of up to 1.2 mm.

Potassium chloride is also commonly crystallised from conventionally mined carnallite ore (KCl, $MgCl_2$, NaCl, $MgSO_4$ and $CaSO_4$). Additional purification steps are generally necessary to obtain a product of the required commercial quality at an economically-acceptable yield.

Potassium nitrate crystallisation

Potassium nitrate (KNO_3) can be manufactured via several process routes:

- GEA offers a direct conversion process for KNO_3 using crude, natural sodium nitrate (caliche) and fertilizer-grade potassium chloride (MOP). This innovative process design provides a capital cost saving on the sodium nitrate rectification plant.
- The reaction of MOP with nitric acid is another KNO_3 production method. This yields ammonium chloride as a by-product.
- Potassium nitrate can also be produced using an ion exchange and crystallisation process.

Ammonium sulphate

The industrial production of caprolactam (CPL), methyl methacrylate (MMA) and acrylonitrile yields large quantities of ammonium sulphate (AS) as a by-product. This route now accounts for 60-70 percent of AS production globally. Other sources of ammonium sulphate include:

- Purge gas washing, e.g. from large urea prilling towers
- Regeneration liquids from continuous ion exchange systems
- Production through reactive crystallisation of ammonia and (spent) sulphuric acid.

The reactive crystallisation of ammonium sulphate produces enough heat of dissolution and reaction that the process can be operated without any external energy source for evaporation. Reactive crystallisation has an energy advantage over evaporative crystallisation but, disadvantageously, produces smaller crystals. Indeed, around 80-90 percent of AS crystallisers are operated in evaporative mode because this produces larger size crystals. The market price of large 'granular' crystals (2-3 mm) can be up to three times higher than the price of smaller crystals (<1 mm) – a price premium that strongly favours the production of large crystals.

PHOTO: GEA

Fig. 4: Ammonium sulphate reactive crystalliser.

Monoammonium phosphate (MAP) from green acid

Monoammonium phosphate (MAP) is manufactured from phosphoric and ammonia by a process involving:

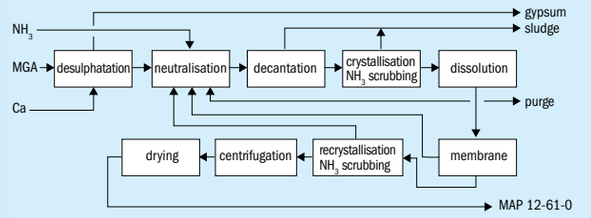
- Reactive crystallisation – the reaction of NH_3 with H_3PO_4 in a reactor
- Decantation
- Membrane filtration
- Forced circulation crystallisers with integrated scrubbers.

This produces MAP in highly concentrated form as white crystalline pellets.

The demand for water-soluble MAP is growing globally. It can be tank-mixed with other fertilizers for fertigation or foliar application to crops. It is notable for the following key attributes:

- Suitable for fertigation and foliar applications, the production of fertilizer blends and nutrient solutions
- Fully water-soluble
- Free of chlorine, sodium and other elements like heavy metals that are harmful to plants
- A safer and less corrosive moderate pH – especially desirable for neutral- and high-pH soils
- Insoluble content below 100 ppm (NTU <10).

Fig. 5: **Block-flow diagram for the production of MAP with the GEA process**



Source: GEA

High-purity phosphoric acid is generally used as the starting product for MAP manufacture. GEA, however, has developed a ground-breaking process for producing high-quality water-soluble MAP fertilizer from non-purified, merchant-grade phosphoric acid (MGA) (Figure 5). This eliminates the need to purchase or manufacture purified phosphoric acid (PPA).

In a major cutting edge 'lighthouse' project for the fertilizer industry, GEA has successfully implemented this process for a customer in Eastern Europe. The installed production unit has avoided considerable capital and operating expenditure, thanks to its ability to consume MGA rather than PPA, yet still produces high-purity MAP fertilizer, a premium product with a high market value.

GEA's process allows the customer to produce pure, soluble MAP with a yield of up to 70 percent. By providing the industry with the ability to manufacture high-quality water-soluble products, GEA is strongly supporting the responsible use of fertilizers.

Innovations and current trends

GEA's newly-developed MAP production concept, which consumes lower grade MGA, incorporates a special **ceramic membrane filtration (CMF)** system for removal of impurities (mainly struvite). The filter's ceramic elements are abrasion resistant and provide the highest level of temperature stability while removing crystalline impurities from the MAP solution. These result from process steps upstream of the CMF filtration system.

Another promising economic innovation is the growing trend for phosphoric acid purification using **high-pressure nanofiltration (NF)** and ion exchange (IEx). This represents a superior alternative to conventional liquid-liquid extraction. The NF membrane system offers world-class performance and achieves good yields at various concentrations. This new method of phosphoric acid purification, by employing acid-stable nanofiltration membranes, avoid the rapid performance degradation associated with conventional polyamide-based membranes. GEA has developed a high-pressure NF unit that can operate at 120 bar g.

In addition to membrane filtration, a polishing stage with **cationic resins** is capable of maximising both crystallisation yield from solutions and product purity. This technology can purify any evaporator feed solution. It can be applied to the purification of phosphoric acid, for example, as well as the production of potassium nitrate.

Fertilizer producers, in the current context of over-capacity, generally seek to optimise their energy costs and consumption, both for competitive advantage and to improve their operational sustainability. In a world of relatively cheap fossil fuels – with even negative oil prices being observed in April 2020 – the imperatives for greater energy efficiency should, in principle, still hold true. With this in mind, there are several ways to improve the energy consumption in evaporation and crystallisation:

- Better use of hot condensates
- Use of vapour recompression
- Installation of multiple-effect evaporators
- Heat integration between the evaporator and dryer
- Combine scrubbing or steam reforming with vapour recompression, when dealing with corrosive process vapours.

GEA is able to provide energy use audits and advise on all these options.

Water and product recovery from fertilizer production effluents is also of growing importance. More stringent regulations on wastewater discharge are driving demand for effective waste reduction and treatment technology. In this context, evaporation and crystallisation can bring great benefits to customers by providing a creative solution to the management of the whole water cycle in industrial processes. The technology enables:

- Compliance with environmental regulations
- Recovery of distilled water
- Recovery of valuable chemicals
- Financial profit from waste treatment
- Highly positive improvements to corporate and social responsibility.

The management of phosphogypsum ponds and raffinates remains a great challenge for the phosphates industry. Evaporation and crystallisation technology, together with membrane filtration and ion exchange, offer one potential solution due to their ability to recover both valuable products and water.

Conclusion

The spectrum of available evaporation and crystallisation technologies can be customised to manufacture a wide range individual fertilizers, allowing these to be produced in an optimal and sustainable manner.

GEA – with a team of 150 evaporation and crystallisation specialists and brands like Messo, Wiegand and Kestner – is a long-standing provider of innovative production technology to the fertilizer industry. Founded nearly 140 years ago, the company possesses invaluable experience of full-scale industrial plants, process design and laboratory- and pilot-scale testing

GEA notably combines extensive expertise in evaporation and crystallisation with strong research and development capabilities. GEA plants producing industrial-grade, high-quality straight fertilizers are found around the globe – in locations ranging from the Atacama desert in Chile to Europe's potash mines, and from the shores of Dead Sea in the Middle East to phosphoric acid plants in Asia and Latin America. ■

About the authors

Laurent Palierne heads the French Chemical Business Unit at GEA Group, while Norbert Strieder is the company's head of Chemical Application Marketing.

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Water-soluble fertilizers: it's crystal clear!

Crystallisation, as a powerful separation technology and production process, is helping the fertilizer industry diversify its product mix, improve profitability and enhance sustainability, as **Sana Boulabiar** and **Matias Navarro**, of Veolia Water Technologies North America, explain.

As with most sectors of the economy, the agricultural value chain has been disrupted by the shock of the Covid-19 pandemic. Adding to existing trade tensions, fertilizer producers have been hit by labour shortages, plant closures, logistics delays and bottlenecks.

Fertilizer producers have been put to the test during this crisis by having to meet urgent and immediate farming needs. Admirably, producers have stepped up their role in ensuring the flow of essential fertilizers to farmers. Supporting agriculture and food availability and affordability is as vital as ever, particularly in a situation of growing food insecurity.

But as lockdown restrictions ease and transportation and distribution start to return to normality, it will be time to think again about the challenges affecting the fertilizer industry in the long run – namely sustainability, resource-efficiency, and economic and environmental viability.

Priorities will undoubtedly shift. This will be a matter of 'when' not 'if'. Greater clarity of purpose will help unlock the long-term challenges overlooked during the immediacy of crisis. Indeed, in our view, the current lockdown provides a valuable opportunity for repositioning our industry as 'providers to farmers of the fertilizers of the future'. Those that can deliver on this ambition and mission statement will be in demand once the world economy and agriculture thrives again.

Technology and opportunity

Thanks to crystallisation technologies, water-soluble fertilizers can match all of the attributes that precision farmers are looking for: solid products with full solubility and maximum purity.

PHOTO: VEOLIA

Veolia crystalliser units, Dead Sea Works, Israel.

The crystallisation process typically employs a crystalliser unit followed by solid/liquid separation and drying/cooling steps. Crystallisation – contrary to other production methods such as granulation, prilling, blending or atomisation – is an extremely selective process and a powerful separation tool. It performs two key roles:

- **Production** of crystals with a controlled size and shape
- **Purification** to reach very high purity levels – usually 99 weight percent or higher – and thoroughly remove insoluble impurities.

Only crystallisation can achieve this degree of purification. Impurities are diluted by extracting a purge stream from the crystalliser. This prevents their co-precipitation with the desired fertilizer crystals. Other process techniques can be combined with the initial crystallisation step to further upgrade and purify the product. A second crystallisation step, for example, minimises the waste purge and delivers higher prod uction yields. It also makes it possible to consume lower grade raw materials yet still produce higher value fertilizer products.

From waste to value

The ability to turn waste into a marketable product is another desirable attribute of crystallisation technology. Being able to adapt to different feedstock grades or sources such as waste streams is one of the technology's greatest advantages. Not only does crystallisation help control manufacturing costs, by delivering higher recoveries, it also enhances sustainability through better waste management.

This is most evident in the production of monoammonium phosphate (MAP), the most popular type of water-soluble phosphate fertilizer globally. MAP is produced by adding ammonia to phosphoric acid. Crystallisation technologies enable high-value MAP to be produced using low-grade phosphoric acid as a feedstock. This is beneficial as poor quality acid is typically classed as a waste product with little to no value, unless costly purification steps are carried out.

It seems vital that no fertilizer raw materials should go to waste, given their growing scarcity and the energy used in their extraction and recovery. Crystallisation makes this possible thanks to its ability to consume waste streams and recycle low-grade feedstocks.

Table 1: **Main types of crystalline water-soluble fertilizers (WSFs). These typically combine high solubility and purity with acceptable pH levels.**

Main types of crystalline water-soluble fertilizers (WSFs)		NPK N %wt	P_2O_5 %wt	K_2O %wt	Crystal colour	pH (5%wt solution)
AMS	$(NH_4)_2SO_4$	21	0	0	White	5.5
MAP	$NH_4H_2PO_4$	12	61	0	White	~4.2
DAP	$(NH_4)_2HPO_4$	21	53	0	White	~7.5-8
MKP	KH_2PO_4	0	52	34	White	~4.4
DKP	K_2HPO_4	0	40	54	White	~9
MKDP	$KH_5(PO_4)_2$	0	60	20	White	~2.2
NOP	KNO_3	13	0	46	White	7-10
MOP	KCl	0	0	60	Red to white	~7
SOP	K_2SO_4	0	0	53	White	~7

Source: Veolia

Product diversification

A growing range of speciality fertilizer products has entered the market, enabling farmers to adopt more sustainable management practices. Crystalline water-soluble fertilizers, for example, have very low levels of sodium, chlorine, or heavy metals (Table 1). Because of this, these 'value-added' products sell at a premium and can command higher margins compared to conventional commodity fertilizers. The ability to manufacture speciality fertilizers helps producers build a more competitive and resilient product portfolio by bringing to market value-added products with exceptional purity and solubility.

Fertilizer producers, through product differentiation and diversification, can also mitigate their exposure to the cyclical nature of the commodity fertilizer market, and insulate themselves from price volatility and/or market shocks in specific agricultural segments (staples, row crops, etc.). Shifting production to water-soluble fertilizers (WSFs) and enhanced efficiency fertilisers (EEFs) also sidesteps the looming regulatory tightening that is expected in response to the environmentally-damaging nutrient losses associated with leaching and runoff.

Production success stories

Alkimia Group is a leading Tunisian chemical company specialising in the production of phosphate salts for industrial applications. The group will soon diversify and benefit from new revenue streams when it commences operation of a new 25,000 t/a capacity monoammonium phosphate (MAP) plant. The new manufacturing line will export this added-value fertilizer product from Gabes, Tunisia, to agricultural growth markets elsewhere in Africa.

Alkimia's new MAP plant, designed and delivered by Veolia, integrates two crystallisation stages with centrifugal separation, drying, cooling, and screening systems. The plant consumes merchant-grade phosphoric acid (MGA, a relatively low-grade acid) and ammonia to produce fully water-soluble, high purity (99 wt % minimum) MAP crystals with very low insoluble content (below 0.2 wt %). The plant design adopted by Alkimia followed a series of laboratory tests carried out by Veolia to simulate and develop the correct process flowsheet.

Potassium sulphate (SOP)

North American crop nutrient and salt producer **Compass Minerals** needed to expand potassium sulphate (SOP) production at its Ogden plant in Utah in the United States. Veolia successfully integrated its *HPD® PIC™* draft tube baffle crystalliser unit into the existing plant. This converts a brine feed containing schoenite into a high-purity SOP product, marketed by Compass as *Protassium+®*. Veolia simulated and developed the process at its research facility near Chicago before validating the design. Veolia's installed process, thanks to more efficient recycling, has also enabled Compass Minerals to significantly reduce water consumption, relative to the existing SOP plant.

Darkest before the dawn

Maintaining essential agricultural operations and food supply until the Covid-19 crisis passes is the responsible thing to do. But, as the major market distortions of the pandemic subside, investing in the fertilizer needs of precision drip irrigation (fertigation) will, in our view, hold the key to success in the long run.

If we have to learn one lesson from this whole pandemic, it is the importance of having a secure supply of resources, a diversified product mix and an efficient production system – rather than depending on one single product and one market to drive demand and maintain plant operations.

Many producers are under pressure to reduce their capital investment at present, due to tight funding and the uncertainty of current low prices. But taking advantage of government financial support to upgrade fertilizer production technology, under generous credit payback terms, may be a smart way to invest for the future.

The economic stimulus provided by policymakers leaves the fertilizer industry with a window of opportunity. Especially if producers can capitalise on technology improvements to plug the holes in their product mix and production processes, placing their businesses on a more profitable, resilient and sustainable footing.

If the future of water-soluble fertilizers is crystal clear, the path to this future is not. Crystallisation is a delicate, fine-tuned separation process. To be efficient, a deep understanding of chemistry is required to place the most nutrients into each crystal particle. Crystallisation systems save producers money because they are designed to make sure that every raw material is upgraded and not wasted. The technology also makes producers more profitable because crystalline fertilizers command higher margins, due to their unmatched purity and solubility, so ensuring a rapid return on the required investment.

Veolia's HPD® evaporation and crystallisation technologies are supporting the global fertilizer industry by enhancing the value of products and optimising their production economics – thanks to our deep fertilizer crystallisation experience, know-how and state-of-the-art research and development capabilities. ■

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Prayon's first industrial DA-HF plant

The DA-HF phosphoric acid process has been successfully implemented at Grupa Azoty's Police fertilizer production plant in Poland, as part of a revamp of the site's existing DH plant. **Sébastien Havelange** and **Alexandre Wavreille** of Prayon Technologies outline the performance improvements achieved by this first-of-its-kind plant.

The world faces ever growing environmental challenges, making the development of new industrial technologies increasingly essential.

Today, most of the world's phosphoric acid is produced via the DH (Di-Hydrate) process route. For some years now, Prayon has been developing an improved phosphoric acid production process known as DA-HF (Dihydrate Attack-Hemihydrate Filtration). These are also the initials of Dorina Fati and Antoine Hoxha, the two Prayon researchers who developed the process.

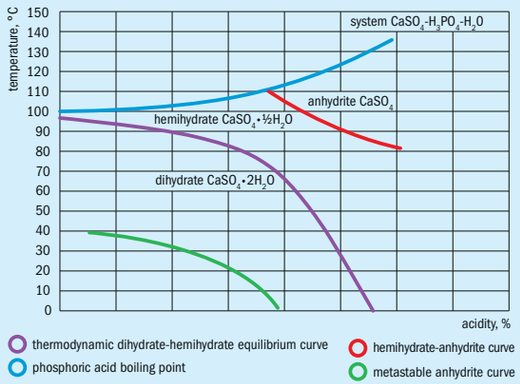
DA-HF and its underlying assumptions have been thoroughly tested at pilot-scale at Prayon's Engis site in Belgium. Recently, the DA-HF process has also been demonstrated at full-scale commercially with the installation of an industrial plant at Grupa Azoty's Police site in Poland.

Compared to the standard DH process, Prayon's DA-HF process has a number of distinct advantages:

- The weak product acid contains higher P_2O_5 levels of up to 34 percent.
- This allows merchant grade acid (MGA, 54% P_2O_5) to be produced using smaller concentration units.
- A higher process efficiency with P_2O_5 recovery above 97 percent.
- Less water is consumed during washing of the calcium sulphate cake.
- Compared to the DH process, the hemi-hydrate (HH) calcium sulphate by-product obtained is potentially more recoverable and suitable for use in cement plants. This is due to its lower P_2O_5 content and its self-drying behaviour when it naturally rehydrates to DH.

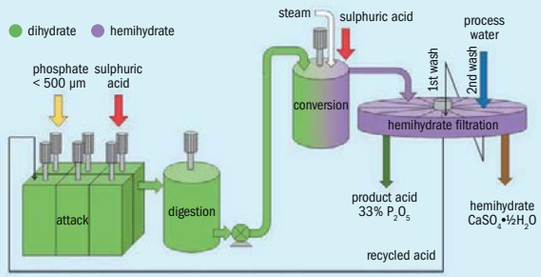
As already stated, the first plant in the world to run this process is currently operating in Poland for Grupa Azoty, Police. This plant was engineered by Desmet Ballestra – who also helped commission the plant in collaboration with a team from Prayon Technologies in 2019. Some results from this first-of-its-kind plant are now available and are presented in this article.

Fig. 1: **The calcium sulphate crystallisation system in phosphoric acid production**



Source: Becker, 1983

Fig. 2: **DA-HF process description**



Source: Prayon

DA-HF process description

The DA-HF process is based on the phase diagram for calcium sulphate (Figure 1). This shows how different forms of calcium sulphate crystallise, according to temperature and global acidity (including sulphate content).

DA-HF is a double-crystallisation process (Figure 2). The first attack of the rock with sulphuric acid results in the crystallisation of DH in a reaction tank at low sulphate levels. DH is then converted into HH at higher sulphate levels (3-3.5% SO_3) in a conversion tank. The conversion is then followed by filtration to recover the high P_2O_5 content acid. This two-step double-crystallisation process, with different sulphate contents, is beneficial as it minimises both unreacted and co-crystallised P_2O_5 losses.

Unlike the very high efficiency CPP (Central Prayon Process) operated by Prayon in Engis, Belgium, only one single filtration stage is required in DA-HF. This makes DA-HF simpler and easier to operate compared to CPP.

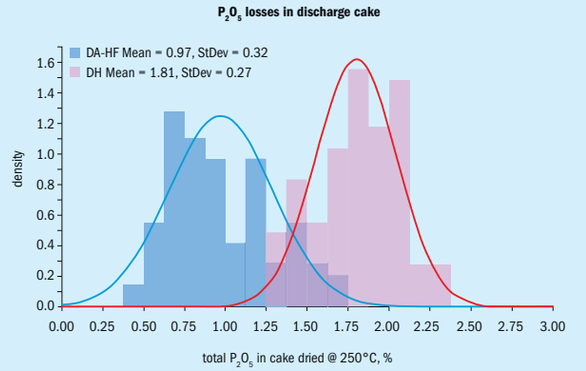
With the conversion operating at 3-3.5 percent SO_3, the sulphate content in the product acid is higher than with the DH process. However, this can be easily reduced, if necessary, by installing a desulphation unit.

First industrial results

The DA-HF process has been successfully implemented in Grupa Azoty's plant in Police, Poland, as part of a revamp of the site's existing DH plant. To simulate Grupa Azoty's production conditions, successful tests were completed at Prayon's R&D centre prior to the full-scale implementation.

The revamping project for Grupa Azoty at the Police site mainly involved the installation of a conversion tank and the modification of the existing tilting pan filter and gypsum evacuation to enable it to handle hemihydrate filtration cake. The revamp increased nominal plant capacity from 420 tonnes of P_2O_5 per day to 500 t/d. The revamp was designed to provide production flexibility – as it allows the plant to still operate in standard DH mode, if necessary, with the conversion tank operating as an extra standard digestion tank. Nominal production capacity is also increased in DH mode due to this extra tank.

Fig. 3: **P_2O_5 losses in discharged cake for the Grupa Azoty phosphoric acid plant: DH (right) versus DA-HF (left) modes**



Source: Prayon

After completing performance tests and the first technological start-up run, it has now been possible to collect statistically representative results for the new DA-HF plant (Figure 3).

Figure 3 shows the distribution of P_2O_5 losses (within the discharged cake) for Grupa Azoty's plant running in DA-HF and DH modes after revamping. Analysis of these results shows that, after applying a *Student's t-test* to the data, there is a significant difference between losses in DA-HF and DH modes with, promisingly, significantly lower P_2O_5 losses for the plant in DA-HF mode. The results therefore conclusively demonstrate that plant efficiency is significantly higher when operating in DA-HF mode.

Initial results also show that considerably more cadmium is removed from the phosphoric acid end-product in DA-HF mode, compared to DH mode, due to its concentration in solids.

Conclusion

This article briefly describes the DA-HF process and its key advantages, compared to the standard DH process that is most widely operated around the world currently. We also show the performance improvements achieved following the conversion of an existing DH phosphoric acid plant into a DA-HF plant by Prayon Technologies, as part of a revamp project for Grupa Azoty. This first-of-its-kind DA-HF plant increased:

- Plant P_2O_5 capacity from 420 t/d to 500 t/d
- Its global efficiency – with total P_2O_5 content in the discharged cake decreasing from 2.5 percent to 1.2 percent
- The P_2O_5 content in the product acid to 32-33 percent
- The quality of the calcium sulphate by-product.

The first results for this industrial plant demonstrate that the limited investment costs and modifications needed as part a DH plant revamp will rapidly be compensated by the multiple advantages DA-HF can offer. ■

About the authors

Sébastien Havelange is a process engineer and Alexandre Wavreille a senior process engineer at Prayon Technologies.

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