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Rice fertilization

India market report

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Phosphate and potash mining

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Cover: *Indian women going to work in a rice field, Tamil Nadu, near Thanjavour, India.*
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Drip irrigation

Innovations in froth flotation

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BCInsight

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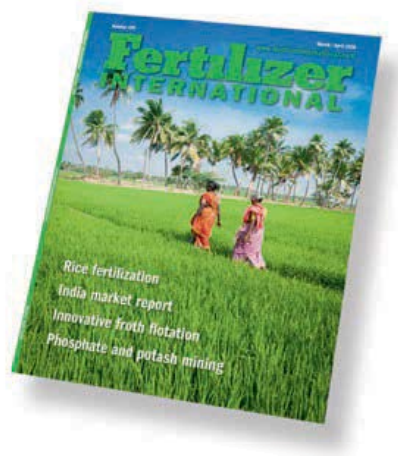
REGULARS

The state we're in



The end of winter each year is always a good time to reflect on the state of the fertilizer industry. This year was no exception with the usual flurry of fourth-quarter and full-year results for 2019 emerging mid-February. Less of a flurry, actually, more of an avalanche.

That makes sifting and sorting every fact and figure for all the fertilizer majors a time consuming business. Thankfully, there are shortcuts.

You can gain a reasonable snapshot of the state of the fertilizer industry from the annual results of the largest companies by market capitalisation – say Nutrien, Yara International, The Mosaic Company and CF Industries, for example.

All four of these major companies operate international-assets and make global customer sales. 2019 was certainly an interesting year for these 'Big Four' fertilizer producers.

Nutrien's take on 2019 was the delivery of stable earnings in a challenging year. The overall picture was certainly solid with the Canadian fertilizer giant reporting marginal year-on-year (y-o-y) increases in sales and earnings* – both up by two percent to $20 billion and $4 billion, respectively.

The year didn't end well, though. Nutrien's potash earnings fell 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. As a consequence, Nutrien posted a net loss of $48 million for the fourth-quarter, despite a strong retail performance.

"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.

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

Impressively, Yara's earnings improvement was achieved against the backdrop of a slight fall in annual revenues – less than one percent – to $12.9 billion, linked to lower fertilizer prices.

"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.

North America experienced its wettest 12 months in almost 50 years in 2019. This negatively affected spring and fall applications and sales volumes, which in turn pressured prices. The Mosaic Company suffered during these difficult trading conditions, reporting a net loss of $1.1 billion for 2019.

These losses reflected $1.46 billion in non-cash charges. These were incurred from Mosaic's permanent closure of its Plant City phosphates production site, the acceleration of potash production at its Esterhazy K3 mine and the idling of the Colonsay potash mine.

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

"Our actions to manage our portfolio of assets and lower our cost structure, our reduced inventories, leave us with tremendous opportunity to capitalize on the improving trends we've seen early this year," O'Rourke said.

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.

Illinois-headquartered CF Industries increased its full-year earnings to $1.6 billion in 2019. Higher average selling prices across its major products – except in the fourth-quarter – also prompted a slight rise in 2019 net sales to $4.6 billion.

"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 enabled us to generate more than $900 million in free cash flow [and] strengthen our balance sheet."

Encouragingly, free cash flow – a useful measure of company profitability – warranted frequent mentions in full-year results. The CEOs of Nutrien, Yara and CF all chose to highlight the generation of strong free cash flow in 2019 – a sure sign of company and collective industry health.

Even the sector's Big Four don't provide us with the whole picture, though. *Fertilizer International* will therefore be taking a deeper dive into the 2019 performance of all the leading listed fertilizer producers in our May/June issue. ■

"The CEOs of Nutrien, Yara and CF all chose to highlight the generation of strong free cash flow in 2019 – a sure sign of company and collective industry health.

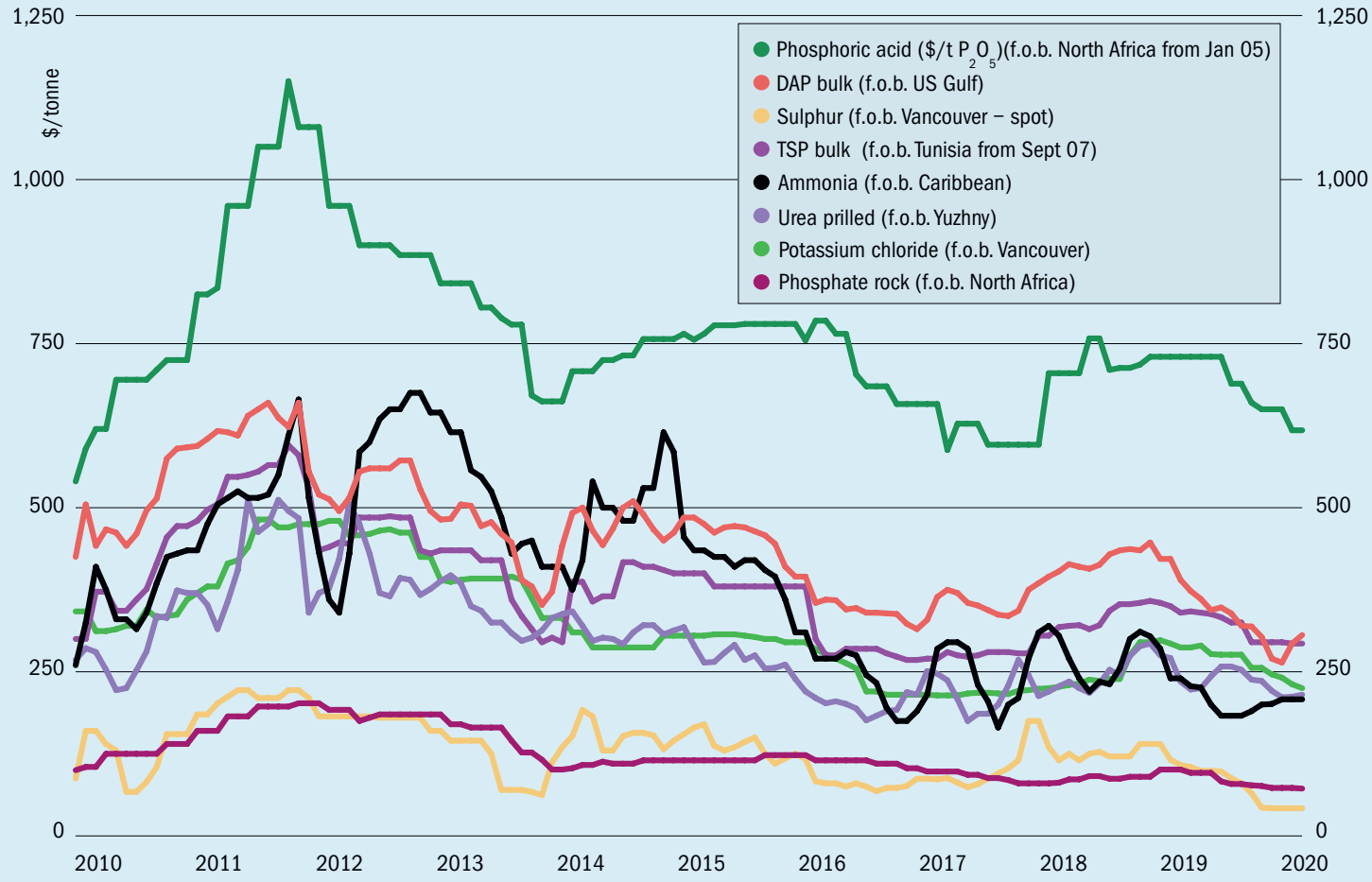
** Earnings throughout refer to adjusted EBITDA.*

S. Inglethorpe

Simon Inglethorpe, Editor

Market Insight

Historical price trends $/tonne



Source: BCInsight

Market Insight courtesy of Argus Media

PRICE TRENDS

Urea: Prices rose in February, driven upwards by high demand and coronavirus concerns. Heavy US buying and trader positioning saw producers sell out early for March. Reduced export availability from China – linked to the impact of coronavirus on production – also contributed substantially to the price hike. The US market pulled up prices almost single-handed. Nola prices rose by nearly $40/t to $270/t cfr with almost 500,000 tonnes of urea being bought.

Phosphates: Prices stabilised in many parts of the world during January and February, and even began to rise, as multiple production cutbacks finally began to take effect. The rise was led by Brazilian MAP prices. These climbed from $278/t cfr in late December to $325/t cfr in late February. This was accompanied by higher prices in the US barge market, with Nola DAP prices rising by $45/t to $281/t f.o.b. over the same period. Europe followed a similar trend. DAP prices there rose from $318/t fca Ghent in December to $345/t fca in February, as importers sought to cover demand ahead of the spring application season.

DAP price levels east of Suez, in contrast, remained flat for much of the first-quarter due to the general absence of demand. Chinese export prices rose marginally from $293/t to $298/t f.o.b. between end-December and the end of February. Supply and demand in China have both been constrained significantly by the coronavirus outbreak. A third of Chinese phosphate production is located in Hubei province, the outbreak's epicentre. Indian DAP prices were similarly stable over the same period, rising by just $10/t to $308/t cfr.

Potash: In February, Argus cut its global potash (MOP) consumption projections for 2020 to 66.7 million tonnes. This one million tonne drop on the previous projection was linked to a variety of factors, including downgraded economic growth forecasts, weather conditions, and the impact of the coronavirus outbreak on buying.

Sulphur: Prices trended flat-to-firm across January and February, contrary to market expectations. A combination of factors have pushed cfr prices steadily upwards as those seeking prompt loading cargoes have been forced to pay up. Russian sulphur producer Gazprom had just 200,000 tonnes available for export in the first quarter. Supply limitations were compounded by maintenance works in Saudi Arabia and bottleneck issues affecting loading at the UAE's Ruwais port.

In China, fallout from the evolving coronavirus outbreak has forced key consumers to remain offline or operate at severely reduced rates. As a result, sulphur inventories at Chinese ports have climbed to 3.1 million tonnes, their highest ever recorded level. Despite record high inventories, prices have continued to rise (both ex-works Yn/t basis and cfr basis) because of the lack of import and replenishment options.

Market price summary $/tonne – End February 2020

Nitrogen	Ammonia	Urea	Ammonium Sulphate	Phosphates	DAP	TSP	Phos Acid
f.o.b. Caribbean	200-215	-	f.o.b. E. Europe 112-126	f.o.b. US Gulf	307-314	-	-
f.o.b. Yuzhny	218-233	212-225	-	f.o.b. N. Africa	299-312	275-320	560-675
f.o.b. Middle East	225-235	236-258**	-	cfr India	308-313	-	590*
Potash	KCl Standard	K_2SO_4	**Sulphuric Acid**		**Sulphur**		
f.o.b. Vancouver	190-255	-	cfr US Gulf	68-80	f.o.b. Vancouver	38-45	-
f.o.b. Middle East	213-262	-	-	-	f.o.b. Arab Gulf	37-50	-
f.o.b. Western Europe	-	458-507	-	-	cfr N. Africa	55-70	-
f.o.b. Baltic	200-260	-	-	-	cfr India	55-70+	-

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.*

MARKET OUTLOOK

Urea: The market looks set to remain firm in March with producers heavily committed and traders attempting to push up prices before selling long positions. Export supply out of China will remain very low through March and April, as the Chinese government has told producers to focus on domestic supply to mitigate the impact of the coronavirus outbreak. Argus believes, however, that price rises will still slow in March. Much of the expected increase in global prices has already taken place, in our view.

Phosphates: In the short term, prices look set to stay firm, both in Europe and west of Suez, given the constraints on supply and current levels of demand. Nevertheless, the picture could change when significant additional supply returns to the market towards the end of the first-quarter. Mosaic has announced that it will resume full phosphate production in March, for example, while Morocco's OCP, Russia's PhosAgro and Tunisia's GCT will all ramp-up their output in March as well. DAP prices east of Suez look more stable. Indian buyers will continue to source DAP to replenish inventories, but supply from Jordan and Saudi Arabia has tightened. Chinese output, meanwhile, is poised to ramp-up, albeit with little import interest from Pakistan.

Potash: Demand in 2020 is still expected to increase by 1.9 million tonnes year-on-year, raising demand to levels last seen in 2018. This demand increase is, however, largely a knock-on effect of China not settling its contracts in 2019, with some contribution from US restocking. With potash stocks high globally, product already in the supply chain could be enough to meet this year's demand requirements, without the need for extra production. Therefore, unless there are further production scale-backs, producers may be forced to temporarily close mines at the top of the cost curve until prices recover. Coronavirus impacts remain the wild card. These could easily negate the projected potash demand increase for 2020, although the overall impact of the crisis is still hard to gauge currently.

Sulphur: Prices are expected to continue on a flat-to-firm path for the rest of the first-quarter – as no improvements in spot availability are anticipated in the near term. Russian supply will return to the market in the second-quarter with the opening of the Volga Don river system for transportation. Supply restrictions due to maintenance will generally also come to an end, with the notable exception of the US. Despite improving availability, price softening is not likely to kick-in until end-April to early-May. This is because spot buyers who have struggled to find product for March loading will immediately snap-up any product offered by April loaders.

PHOTO: MOSAIC

Mosaic is ramping up production at its Esterhazy K3 mine expansion.

CHINA/WORLD

Coronavirus pandemic hits commodity markets

The grave economic and human health consequences of the global spread of coronavirus (*Covid-19*) deepened in March.

Italy moved into national lockdown on 9th March, a move replicated in Spain a week later. The World Health Organisation also formally declared coronavirus a global pandemic on 11th March. The US responded by introducing a flight ban from EU countries from 14th March, before extending this to cover the UK and Ireland.

Shares around the world have also plunged with investors fearing the spread of the virus – and the inability of governments to halt this – will destroy economic growth.

The main UK FTSE 100 index dropped more than 10 percent on the 12th March, its worst day since 1987. In the US, meanwhile the Dow and S&P 500 were also hit by their steepest daily falls since 1987.

Oil prices also slipped to $30 per barrel in the second week of March on the news of virus-related factory shutdowns, a situation exacerbated by Saudi Arabia and Russia ramping-up their oil production.

The International Fertilizer Association (IFA) and CRU reacted to the growing transmission worries by cancelling the CRU Phosphates 2020 event in Paris, and postponing the 88th IFA Annual Conference in New Delhi. These were scheduled to take place in early March and late April, respectively.

The spread of *Covid-19* in China and Italy has given markets a sobering indication of what to expect in other countries globally. The outbreak in China – the world's second-largest economy, responsible for almost a fifth of global GDP – is having a significant impact on commodity markets, as trading patterns are disrupted and economic growth forecasts are revised downwards.

The scale of the impact emerged in a white paper published by analysts Argus in late February. "From a commodities markets perspective, it is arguable that the economic damage is already done and quantifiable," said Argus, commenting specifically on the situation in China and it wider international repercussions.

Slowdowns in demand for commodities, and supply-side disruptions, look almost certain. The main debate now is about the scale of these impacts and their consequences for commodity producers, traders and distributors.

The International Energy Agency (IEA), for example, has cut its 2020 forecast for crude oil throughput at refineries globally by 600,000 b/d to 82.7 million b/d, reports Argus. The heaviest downward revisions – as much as one million b/d – occur in first quarter, with China accounting for half the drop. The IEA was previously forecasting a 300,000 b/d year-on-year increase over this period.

Argus is, however, projecting a more modest downward revision to oil demand of 380,000 b/d over the course of 2020. This projection is based on the *Covid-19* pandemic causing a hit to the global GDP of just 0.3 percent. Argus does, however, caution that: "It is highly unlikely that the virus has finished springing its surprises – both psychological and real – for oil or the wider commodity markets."

Rabobank is reporting that the utilisation rate in China's fertilizer industry has dropped by about 30-40 percent year-on-year since the outbreak began.

Chinese phosphate production has been particularly badly hit by the spread of *Covid-19*. Hubei, the province at the epicentre of the outbreak, is responsible for almost 30 percent of China's total phosphate production capacity. Mosaic estimates that Chinese phosphates production losses exceeded two million tonnes in the first-quarter. Companies in the province were not scheduled to reopen until 11th March.

To help Chinese industry restore production in the aftermath of the outbreak, state-owned China Railway cut rail transportation costs by up to 50 percent in early March. The move, which is scheduled to last until the end of June, should help restore distribution, given that rail transport is essential to fertilizer logistics within China. In a boost to urea and ammonia producers, NDRC, China's main economic planning agency, is also reducing gas costs to aid industries affected by the *Covid-19* outbreak.

According to Argus, the government in China is pushing fertilizer producers, local agriculture agencies and transportation providers to maintain fertilizer supplies. It is also urging farmers to continue crop planting during the spring season. Encouragingly, curbs on transportation have been eased in some areas, with early indications that domestic fertilizer sales are starting to rise.

This has not prevented the impact of the outbreak from spilling across China's borders and affecting its major trading partners. Curbs on movement have halted agricultural imports from Vietnam and Myanmar since early February. Such measures, reports Argus, have left containers of fruit rotting at the border. Melons from Myanmar, dragon fruit from Vietnam and durians from Thailand are among the worst affected products.

China is a significant regional export destination for fruit. A lengthy halt to agricultural trade would therefore hit farm incomes in Southeast and East Asian countries. This in turn could hurt regional demand for fertilizers such as NPKs, says Argus.

Financial Times is reporting, based on an analysis by John Hopkins University, that major economies – France, Germany, Iran, Italy, South Korea, Spain, the UK and the US – are currently all following the same outbreak trajectory, with around one-third extra cases being confirmed daily. This suggests that the economic impacts of the pandemic will continue to magnify for at least several months ahead.

Italy has seen the largest European *Covid-19* outbreak to date. Yet the country's fertilizer market has yet to feel a major impact from coronavirus, Argus reported in mid-March, despite the introduction of stringent national measures to contain the outbreak.

Many in the industry will be monitoring the spread of *Covid-19* in India, a key demand market for nitrogen, phosphate and potash fertilizers, and a mainspring of growth for the entire global fertilizer industry. ■

UNITED KINGDOM

Anglo American buys Sirius Minerals

Anglo American's £405 million buyout of Sirius Minerals is to go ahead after gaining shareholder approval.

Sirius shareholders formally backed the takeover at a meeting in London on 3rd March. Sirius' directors successfully headed-off a rebellion by small investors by winning the support of the majority of individual investors.

At what was described as a fractious meeting, the company's sale to Anglo was supported by 62 percent of individual Sirius shareholders. The deal also received 80 percent support by total share value, significantly above the 75 percent threshold required.

Previously, Sirius had successfully raised $1.2 billion (£920 million) of 'stage 1' finance for its under-construction Woodsmith mine in North Yorkshire, near Whitby, close to England's North Sea coast. But that still left the junior mining company needing a further $3.8 billion to fully develop the project and deliver on its ambition to become the world's biggest polyhalite producer.

Anglo American has purchased Sirius Minerals at a price of 5.50 pence per share. This has left many shareholders out of pocket, given that Sirius shares were valued above 45 pence going back to September 2016, although they were trading at just over four pence a share immediately before Anglo's approach was revealed. Around half of the company's shareholders are 85,000 retail investors, many of whom live in Yorkshire where the mining project is located,

Sirius Minerals CEO Chris Fraser reportedly told shareholders at the deciding meeting: "This isn't a great price but it is the price," while adding that the failure to secure the necessary financing to complete the Woodsmith mine was the "greatest failure of my career".

The board of Sirius Minerals unanimously recommended that shareholders vote in favour of Anglo American's offer, warning there was a high probability the business would be placed in administration or go into liquidation if the deal was rejected.

Russell Scrimshaw, chairman of Sirius Minerals, said: "The positive outcome from today's meeting secures a return for shareholders, and provides greater certainty in terms of safeguarding the project, protecting the jobs of our employees, and allowing the community, region and the UK to continue to benefit."

Anglo American has said previously that it will broadly keep to the latest development plan for the Woodsmith mine published last November (*Fertilizer International* 494, p8), with the caveat that it would need to "update the timeline, optimise mine design and ensure appropriate integration with its own operating standards and practices".

Dealings in Sirius Minerals shares were suspended in London from 16th March, following shareholder approval of the takeover. Anglo American's purchase of the company was scheduled to be completed on 17th March.

UNITED STATES

K+S to divest its salt business

K+S has announced it is to sell its North and South American salt business to pay down debt. It will now focus on producing and selling fertilizers and speciality products instead.

K+S expects the sale to be agreed by the end of the year. 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," said Burkhard Lohr, chairman of K+S.

The divestment is part of the company's plan to reduce its debt by more than two billion by 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 on the basis of solid financial resources. 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," added Lohr.

K+S said it would reveal more details of the salt business sell-off and its plans for restructuring once the sale was agreed.

IFA puts sustainability centre stage

The International Fertilizer Association (IFA) highlighted its commitment to sustainability by convening the industry's first ever Global Stewardship Conference in New York in early February.

IFA welcomed 170 leaders from the global fertilizer industry and the wider business community to the event at the Lotte New York Palace hotel from the 3rd to 7th February. *Fertilizer International* was pleased to support the event as IFA's official media partner.

The conference linked urgent international obligations, such as the 2016 Paris Agreement and the UN's Sustainable Development Goals (SDGs), with specific actions on sustainability and product stewardship being taken by the fertilizer industry.

The event enjoyed high level support, with the CEOs and chairs of some of the fertilizer industry's biggest names attending and participating. This was a recognition that sustainability – by providing a social licence to operate and reducing reputational risks – is now becoming as important to companies as market share and shareholder value.

The conference was opened by Mostafa Terrab, IFA's current chair and the chair of Morocco's OCP Group. He welcomed a diverse range of delegates, including fertilizer industry CEOs, safety, health and environment (SHE) experts, agronomists and public affairs professionals. Policymakers, engineers and leading figures from intergovernmental bodies, NGOs, academia and business also attended.

The conference included presentations on fertilizer production, technological innovation, energy and water efficiency, and emissions reduction. The positive contribution fertilizers can make to soil health and biodiversity were also high on the agenda – as were efforts to improve nutrient use efficiency and minimise nutrient losses to the environment.

Many external speakers spoke about the fertilizer industry's crucial role in the shift towards more sustainable agriculture. "Our food system is bankrupting our healthcare system and the fertilizer industry is critical for addressing this," said Roy Steiner, a senior VP at the Rockefeller Foundation. Ann Tutwiler of the Meridian Institute and SystemIQ explained how the fertilizer industry

could play a major role in helping countries implement agrobiodiversity as a way of mitigating climate change risks.

On sustainable fertilizer production, Peter Levi, a leading analyst at the International Energy Agency, thanked IFA for its input into the development of a Nitrogen Technology Roadmap. This is seeking to significantly improve energy efficiency and reduce the nitrogen industry's carbon footprint.

Speakers were keen to highlight the fertilizer industry's growing focus on sustainability. "Sustainability is business, not something a company does in addition to business," observed Candace Laing, VP of sustainability & stakeholder relations at Nutrien. Although sustainability required investment, agreed Tip O'Neill, CEO of IRM, it "represents a huge market opportunity and leads to measurable returns". Ben Pratt, VP of public affairs at Mosaic, strongly advised that the industry cannot afford "to step back from social and environmental responsibilities".

The sustainable production and application of fertilizers – and the ability of the fertilizer industry to support sustainable food systems and help mitigate climate change – were key conference themes. "I am optimistic that through capital deployment, accelerated innovation and courageous leadership, the fertilizer industry will deliver in collaboration with communities and citizens," said Devry Boughner Vorwerk, CEO of DevryBV.

"As the fertilizer industry takes an increasingly holistic approach to stewardship, we were delighted to have had such prestigious speakers, as well as a wide range of excellent presentations from IFA members from across the world detailing their impressive sustainability initiatives," commented Charlotte Hebebrand, IFA's director general.

IFA have decided to run the event again next year due to the success of this year's inaugural conference.

A full report on IFA's Global Stewardship Conference in will appear in the May/June issue of *Fertilizer International*.

Weir launches three new pumps

Weir Minerals has launched three new pumps for the sulphur, sulphuric and phosphoric acid industries.

These expand the company's already well-established and market-leading *Lewis*® range of pumps and valves.

All three new pumps have been designed to maximise wear life and simplify maintenance. Weir says it has been able to significantly reduce the number of parts, compared to previous pumps, without compromising their performance.

The new Lewis horizontal process pump incorporates corrosion- and wear-resistant *Lewmet*® alloys. It also delivers the robust performance, efficiency and ease of maintenance usually associated with centrifugal pumps. This single-stage, end-suction pump is suitable for a wide variety of chemical processing applications.

The heavy-duty construction of the new Lewis VL axial flow pump makes it well-suited for corrosive, high-temperature chemical processing applications such as evaporator and crystalliser circulation. Its innovative design allows it to be customised to suite a wide variety of industrial applications. The pump is also easier and quicker to service due its low number of component parts.

The Lewis vertical high-pressure molten salt pump has been specifically designed for use in the emerging concentrated solar power (CSP) industry. This multi-stage, vertical turbine pump is able to handle the extremely high pressures and temperatures associated with pumping molten salt for thermal energy storage. It can be expanded from three to 14 stages. It also features an integrated

protective thermal barrier, a non-contacting shaft seal and a low NPSH (net positive suction head) first stage.

"Although they're designed to address different challenges, these three new pumps were guided by the same core design principles: using advances in material technology to achieve increased performance and wear life, while reducing complexity to simplify equipment maintenance and give us the flexibility to deliver more engineered-to-order features that benefit our customers," said Jerry Ernsky, Lewis product manager, Weir Minerals.

DuPont launches *Sennuba*™ technology

DuPont Clean Technologies has introduced a new steam plume suppression system for wet scrubbing in sulphur recovery units (SRUs).

DuPont's *Sennuba*™ system is being paired with the company's existing *MECS*® *DynaWave*® scrubber in this application.

The new system employs two heat exchangers and a heat transfer medium to heat stack gas from wet scrubbers. By recovering heat from the process that would otherwise be lost, this visible plume suppression system avoids the high operating costs associated with other methods of steam plume control.

"Our aim was to develop a solution that would offer the refining industry a cost effective, simple to operate and low maintenance plume suppression technology for its SRU scrubbers," says Yves Herssens, global licensing manager for scrubbing technologies at DuPont Clean Technologies. "*Sennuba*™ offers reliable plume suppression and corrosion control in a scrubbing system that is at minimal risk of plugging."

JORDAN

Veolia to expand potash plant capacity

Veolia Water Technologies has won a contract to expand production capacity at a leading potash fertilizer plant in Jordan.

Veolia say it will install *HPD*® crystallisation technology at the plant to extract high-quality potash fertilizer from Dead Sea brines.

The plant's existing crystallisers will be replaced with new *HPD*® crystallisation systems. These will improve the processing of carnallite feedstock – a mixture of magnesium chloride and potassium chloride – and increase the extraction of the water-soluble potash end-product. Veolia will also upgrade the barometric condensers which handle vapour generated by the new crystallisers.

These equipment upgrades and new installations will improve the plant's efficiency and deliver energy savings, according to Veolia.

"We are delighted to support world-class producers in the extraction of essential potash crop nutrients for boosting agricultural productivity in Asia, Africa, and the Middle East," said Jim Brown, CEO of Veolia Water Technologies Americas. "This is a testament to the value of the crystallization expertise we bring to the fertilizer industry".

In a statement, Veolia confirmed it had secured a contract to "modernize a refinery on the southern shores of the Dead Sea", adding that this would raise its production capacity to 1.5 million t/a.

Although the customer has not been named, it is likely that the expansion project was awarded to Veolia by Jordan's Arab Potash Company, a major regional producer.

Veolia Water Technologies did not disclose the value of the contract.

NIGERIA

Dangote plant in pre-commissioning

Dangote's large-scale urea-ammonia complex near Lagos, Nigeria, has finally entered pre-commissioning, the company has confirmed.

The giant fertilizer complex is located in the Lekki Free Zone close to Nigeria's Atlantic seaboard, and has the capacity to produce three million tonnes of granulated urea annually.

The project to complete the $2 billion complex is now in its final stages and approaching completion. Italy's Saipem is constructing the plant, being the project's engineering, procurement and supervision contractor. Tata Consulting Engineers of India are acting as project management consultants.

Virtually every section of the urea production complex – including the central control room, ammonia and urea bulk storage, cooling tower, power generation plant and granulation plant – is now complete and are going through pre-testing, Dangote said in a statement.

The project is also receiving its gas feedstock. The fertilizer plant is being supplied with 70 MMscf/d of natural gas from the Nigerian Gas Company and Chevron Nigeria Ltd under a gas sale and purchase agreement.

Products from the fertilizer plant will save Nigeria $500 million by import substitution and generate $400 million in exports, according to Dangote Group executive director Devakumar Edwin.

"By the time our plant is fully commissioned, the country will become self-sufficient in fertilizer production – and even have the capacity to export to other African countries," Edwin said, adding: "Around five million tonnes of fertilizers are required per year in Nigeria in the next five to seven years – 3.5 million t/a of urea and 1.5 million t/a of NPK, while current production levels in Nigeria [prior to the opening of the new Dangote plant] are 1.6 million t/a."

BOLIVIA

Bulo Bulo plant relocation mooted

The Bolivian government has proposed moving the troubled Bulo Bulo ammonia-urea plant to a "more profitable" location closer to the Brazilian border.

Speaking to Bolivia's state news agency, Víctor Hugo Zamora, the hydrocarbons minister, criticised the decision to locate the plant in Cochabamba state more than 1,000 kilometres away from Brazil, its principal market. Zamora described the $1 billion Bulo Bulo project as the "worst political whim" of former president Evo Morales' government.

However, the practicalities of relocating the plant were questioned by Mario Apaza, Cochabamba's industrial development director for energy and hydrocarbons. He responded to the minister's comments by saying that relocation would not be viable due to lack of raw materials. He also estimated that costs of moving the plant would be around 60 percent of its original capital cost.

Bulo Bulo entered production in January 2018. Nominally, it has the capacity to produce 1,200 t/d of ammonia and 2,100 t/d of urea. But, according to Zamora, the plant has at times been operating at less than 10 percent capacity.

The plant produced 900 t/d of urea on average during 2019. This included 136 days with no production. Bulo Bulo's output has been affected by the plant's remoteness from potential end-markets and poor natural gas supply from declining fields. The plant also recorded a $6 million loss in the first-half of 2019 as global urea prices slumped below $250/t.

A new railway line to Montero to connect Bulo Bulo with the country's eastern rail network also remains unfinished, despite having been under construction

since 2013. This leaves truck transport as the only option for shipping urea from the plant.

The Bulo Bulo plant is currently closed for a three-month revamp.

BRAZIL

Três Lagoas up for sale again

Petrobras has restarted the process to sell the UFN-III urea project at Três Lagoas in Mato Grosso do Sul state.

Brazil's state oil company issued a 'teaser' prospectus for the plant on the 10th February.

The construction of UFN-III began in September 2011 but subsequently stalled in December 2014 leaving the plant 81 percent compete. The plant will have the capacity to produce 2,200 t/d of ammonia and 3,600 t/d of urea once finished, according to Petrobras.

Petrobras had previously attempted to sell off UFN-III as part of a huge $30 billion divestment programme in 2018. More recent negotiations to sell the urea plant – and another in Parana state – to Russian fertilizer producer Acron collapsed last December, after Brazilian authorities blocked the plan.

The Acron deal was also contingent on Bolivia's state-owned YPFB supplying 2.2 million cm/d of natural gas to the plant. This arrangement was thrown into doubt following the resignation of Bolivia's president, Evo Morales, in November.

EGYPT

Aswan nitrogen complex completed

The new Egyptian Chemical Industries (KIMA) nitrogen complex at Aswan is finished and ready to enter production, according to the company.

The new $770 million complex has the capacity to produce 900 t/d of ammonia, 1,200 t/d of urea, and 300 t/d of ammonium nitrate (both low and high density). Full-scale commercial production is expected to start in April, following the successful completion of trial operations.

SPAIN

Highfield signs potash offtake with Keytrade

Australian potash project developer Highfield Resources has signed an offtake agreement to supply Keytrade AG with 300,000 t/a of potash from its under-development Muga potash project in Spain.

The terms were agreed between Geoalcali, Highfield's wholly owned Spanish subsidiary, and the Swiss-based trading company in a memorandum of understanding (MOU) signed in February. The offtake represents about 30 percent of Muga's projected output.

Highfield Resources chairman, Richard Crookes, said: "The signing of another offtake MOU is a very important step in solidifying Highfield's commercialisation strategy. In addition, it is further recognition by the market of the importance of the Muga Mine in the global and local MOP supply space. Keytrade brings many years of experience and a large global network that will be extremely valuable to Highfield."

Keytrade works with fertilizer suppliers, distributors, retailers and other end-users in more than 115 countries globally, through its main offices in Zurich, Madrid, Tampa, São Paulo, New Delhi and Beijing.

People

Charlotte Hebebrand, director general of the International Fertilizer Association (IFA), is to step down at the beginning of May, after more than seven years in the role.

In her farewell letter to IFA members, Charlotte said that it had been "a tremendous privilege" to work with IFA since joining the association in September 2012.

"I will forever be grateful for the trust you placed in me, for your engagement to both build and implement IFA's strategic objectives, and for all the support you have provided to IFA," Ms Hebebrand said. "IFA is a dynamic and vibrant association for a crucially important industry in a fast changing world, and we have a terrific Secretariat and outstanding senior staff, which will ensure a smooth transition."

Although Charlotte is leaving IFA she will not be leaving the fertilizer industry. She was therefore looking forward to keeping in contact with colleagues: "I am very pleased that I will continue to be closely involved in IFA affairs, as I assume my next post as executive vice president at Nutrien …and will be delighted to remain in touch with all of you."

Patrick Heffer, the senior director of IFA's agriculture service, will act as interim director general for several months until a permanent replacement for Ms Hebebrand is found. IFA is aiming to appoint a new director general by July. The candidate will need to be proposed by IFA's board of directors and then approved by the membership at its general meeting.

The Mosaic Company is merging its potash and phosphates operations into one single management team from the start of April. The new combined business will be led from Tampa, Florida, by **Bruce Bodine**, currently senior vice president, phosphates. Bodine has extensive leadership experience in both the potash and phosphates segments of Mosaic's business. **Karen Swager**, currently senior vice president, potash, will take on a new role for Mosaic. She will now lead on North America supply chain, procurement, and corporate environmental, health and safety. Ms Swager will also be based in Tampa, Florida.

Anthony Cina has become the new chairman of Itafos. Anthony was formally appointed to the role by the company's board of directors in February, having served as interim chairman since last November. He has been on the board of Itafos since April 2015 and also chairs the company's audit committee. Mr Cina has extensive executive-level mining industry experience, having served in various accounting, finance and tax roles during his 30-year career. Anthony was previously a senior vice president at Yamana Gold Inc. He was also the chief financial officer of Itafos immediately prior to this. Mr Cina is a chartered accountant and chartered professional accountant. He holds a commerce degree from the University of Toronto.

Linda Dempsey has joined CF Industries as vice president, public affairs. She succeeds **Rosemary O'Brien**, who is retiring after 41 years with CF. Ms Dempsey will take on responsibility for all aspects of global public affairs for the company. She will report directly to Tony Will, CF's president and CEO.

"Linda's proven leadership across trade, investment, regulatory, tax, and other public policy issues will serve CF well in the years ahead," said Will. "We look forward to her strategic counsel and insight as we actively participate in the legislative and regulatory process, drive engagement with our many stakeholders and communicate the broad and positive impact our company has on the world."

Prior to joining CF, Ms Dempsey was vice president, international economic affairs, for the National Association of Manufacturers (NAM). In a varied career, Ms Dempsey has also served on Capitol Hill as a senior trade advisor, enjoyed a stint as a lawyer in private practice, and worked on overseas development in the agricultural sector.

Ian Harebottle resigned as the CEO of South African-based phosphate project developer Kropz Plc at the end of February. The board has appointed **Mark Summers**, currently the company's chief financial officer, as its interim CEO.

Kropz chairman Lord Robin Renwick said: "I and the Board have been extremely grateful for the contribution Ian has made as CEO of Kropz Plc. He kindly undertook not to leave until the company had made progress towards a solution for Elandsfontein."

Harebottle commented: "It has been a privilege to lead Kropz since its IPO, during what has been a challenging period for our industry and the company. Importantly at Elandsfontein we now have a clear pathway to production, supported by a comprehensive funding solution that is at an advanced stage of negotiation. Significant progress has also been achieved at Hinda and for these reasons I believe it is the right time for me to hand over the reins and pursue other challenges." ■

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.

APRIL

20-22 **POSTPONED UNTIL 2021**

88th IFA Annual Conference,
NEW DELHI, India
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

22-24

The Sulphur Institute Sulphur World Symposium, CHICAGO, Illinois
Contact: Sarah Amirie, TSI
Tel: +1 202 296 2971
Email: SAmirie@sulphurinstitute.org

MAY

20-22

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

44the 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

NOVEMBER

2-4

Sulphur and Sulphuric Acid Conference 2020, THE HAGUE, Netherlands
Contact: CRU Events
Tel: +44 20 7903 2167
Email: conferences@crugroup.com

India's fertilizer market

India consumed just under 57 million tonnes of fertilizers in 2018/19, cementing its position as the world's second largest fertilizer marketplace. **MP Sukumaran Nair** provides an update on the country's fertilizer industry, its continuing import reliance and the strong influence of government policy.

Self-sufficiency in food grains

Fertilizers have played a major role in the success of India's 'green revolution' – the transformational improvement in crop productivity seen over the last forty years – and the subcontinent's subsequent attainment of self-reliance in food grain production by 2000. Greater fertilizer consumption has undoubtedly contributed significantly to this step change and the sustainable production of food grains in the country. Indeed, in response to ever rising crop demand, India's annual fertilizer consumption has generally been growing in double digits in recent years.

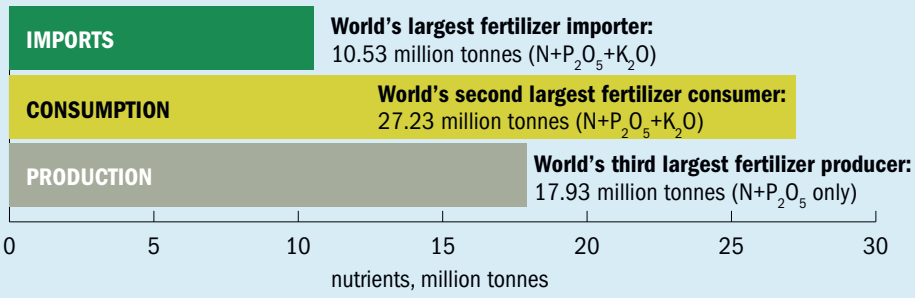
Nevertheless, despite strong growth over four decades, India's average fertilizer application rate remains much lower than in most other developed and emerging countries globally. Furthermore, nutrient usage is highly variable geographically, with wide inter-regional, inter-state and inter-district differences in fertilizer application rates.

The Indian government is mandated to ensure food security for around two-thirds of the population by the 2013 National Food Security Act. To meet this obligation, the country's grain output (mainly rice, wheat, coarse grains and pulses) needs to increase from 285 million tonnes currently to 300 million tonnes by 2021. However, although the country attained self-sufficiency in food grain production in the late 1990s, per capita availability of food grains has faltered in recent years. This setback has been due to slackening growth in agricultural productivity combined with increases in population.

Imminent budgetary boost

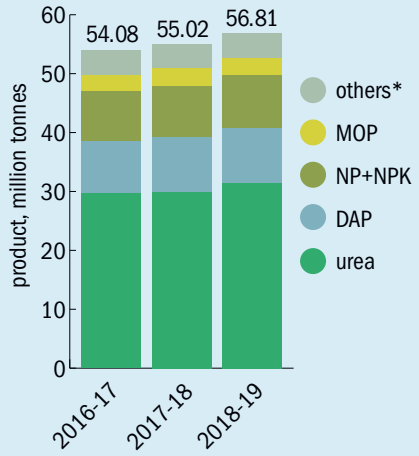
Against this backdrop, the Modi Government, in its 2020 budget, is proposing to revitalise wealth creation throughout India. By applying a fiscal stimulus, the government is aiming to hugely expand the national economy to $5 trillion by 2024, up from $2.6 trillion today.

Fig. 1: **Key Indian fertilizer market facts, 2018/19**



Source: Indian Govt Dept of Fertilizers

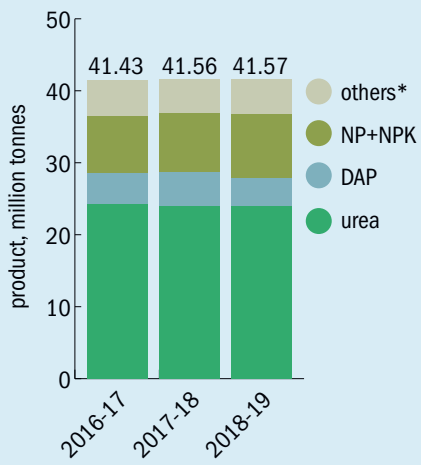
Fig. 2: **Indian fertilizer consumption, 2016/17-2018/19**



**Mostly SSP, rock phosphate and AS*

Source: Indian Govt Dept of Fertilizers

Fig. 3: **Indian fertilizer production, 2016/17-2018/19**



**Mostly SSP and AS*

Source: Indian Govt Dept of Fertilizers

The budget does include worthwhile prescriptions for boosting agricultural productivity and stimulating sector growth – their overall aim being to double farmers' incomes by 2022. Agriculture, although employing 65 percent of India's workforce, currently contributes only 17 percent to national GDP. The new budget singles out agriculture, and allied sectors including irrigation and rural development, making these its prime focus with an allocation of INR 283,000 crore (cr = 10 million rupees), an all-time high.

Fertilizer market overview

India is the world's largest fertilizer importer, second largest market and third largest fertilizer producer (Figure 1).

Urea demand (31 million t/a) is particularly high, accounting for around 55 percent of total fertilizer consumption (Figure 2) Around three-quarters of urea use is met by domestic production (Figure 3) with the remainder (7-8 million t/a) imported (Figure 4).

Most Indian urea plants use natural gas as feedstock which accounts for 70-80 percent of the cost of production. India has insufficient natural gas reserves to meet its national consumption needs. Consequently, the country relies on imported LNG for around 60 percent of its total gas demand.

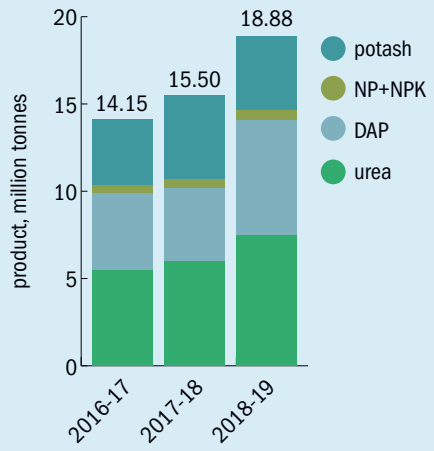
Phosphate, NP/NPK and DAP are the main product preferences of Indian farmers. The combined demand for these two products (18 million t/a) equates to around one-third of total fertilizer consumption (Figure 2).

Around 60 percent of DAP and 7-8 percent of NP/NPKs requirements need to be imported (Figure 4). India is also import-reliant for the majority of raw materials and intermediates (rock phosphate, phosphoric acid, ammonia and sulphur) required by its domestic phosphate production industry.

India is completely reliant on imported potash – for both direct application and NPK blends.

On a nutrient basis, consumption of N and P_2O_5 increased by two percent during 2018/19, while K_2O decreased by six percent year-on-year. The present average Indian fertilizer application of 157 kg/ha for arable land has stagnated and remains depressed relative to advanced agricultural countries.

Fig. 4: **Indian fertilizer imports, 2016/17-2018/19**



Source: Indian Govt Dept of Fertilizers

"Fertilizers have undoubtedly contributed to the step change in food grain production."

Domestic production

Urea production declined marginally during 2018/19. India did, however, commission its first greenfield urea plant in 23 years in January 2019. Most of the country's urea plants are operating at full stretch near to their rated capacities (Table 2).

The government's New Investment Policy was first introduced in 2012 to encourage investments in brownfield and greenfield urea production projects. The aim of the policy, which has been modified several times since, is to reduce India's reliance on imported urea. The response from investors has been generally lukewarm with natural gas availability and supply being major obstacles.

The percentage of domestic gas supply allocated to fertilizer plants declined from 49 percent in 2016/17 to 40 percent in 2018/19. This was largely due to a gas production shortfall from the Bombay High and KG fields. Urea production requirements have instead been increasingly met by imported LNG. The high delivered cost of LNG has, in turn, made domestic urea production increasingly costly. The recent supply deals with US gas producers may, however, ease this situation. Other positive supply news on the horizon includes the expansion of the natural gas pipeline network to 27,000 kilometres and redoubling of efforts to develop coal bed methane, both of these part of the wider overhaul in fertilizer policy signalled by the government's 2020 budget.

The average utilisation rate for Indian urea plants was 92 percent of installed capacity during 2018/19 (Table 2). That compares to an average utilisation rate of only 43 percent for domestic DAP producers (Table 3). These rates show there are clear economic disincentives for domestic DAP production currently, especially given that the same production facilities produce NP/NPKs at an average utilisation rate of 81 percent.

Table 2: **India's major urea producers**

Producer	Production capacity (million t)	2018/19 production (million t)
1. Indian Farmers' Fertilizer Co-operative (IFFCO)	4.242	4.562
2. NFL	3.567	3.860
3. Chambal Fertilizers & Chemicals Ltd	3.353	2.504
4. KRIBHCO	3.059	3.406
5. RCF	2.330	2.376
6. Nagarjuna Fertilizers & Chemicals Ltd	1.520	0.585
7. Yara Fertilizers, India	1.155	1.301

Source: Indian Govt Dept of Fertilizers

Table 3: **India's major DAP producers**

Producer	Production capacity (million t)	2018/19 production (million t)
1. Coromandel International Pvt Ltd	3.225	0.361
2. IFFCO	2.700	1.419
3. GSFC	0.887	0.459
4. Paradeep Phosphates Ltd (PPL)	0.600	0.701
5. ZACL	0.372	0.114
6. Hindalco Industries Ltd	0.400	0.303

Source: Indian Govt Dept of Fertilizers

Rising imports

Imports of finished fertilizer products, their intermediates and raw materials are vital when it comes to meeting the nutrient needs of India's farmers. India is currently

A subsidised market

Fertilizers remain heavily subsidised in India.

Urea support is provided through the administered pricing scheme (APS). This allows producers to sell urea at a government-determined price. In return, the government reimburses producers for their productions costs plus a 12 percent net return. Currently, the market price for urea is set at INR 5,360/t with government providing a subsidy averaging INR 14,000/t, the actual amount depending on the plant's feedstock, technology and operational efficiency (Table 1). As a consequence of its low price relative to other fertilizers, Indian usage has always been skewed towards urea. This results in unbalanced fertilization with soil N: P: K ratios deviating from the optimum 4:2:1 level.

All other fertilizers, with the exception of urea, fall under the nutrient based subsidy (NBS) scheme. The scheme applies to producers and importers of phosphate and potash fertilizers. These companies are free to sell products at market-determined prices, but the government still provides a pre-fixed subsidy for each nutrient (Table 4). The scheme therefore functions to partially de-control pricing.

Table 4: **India: fertilizer subsidy rates, 2019/20**

Urea:	Rs 1,4000/t (av)
DAP/ NPK based nutrients	
Nitrogen:	Rs 18.90/kg
P_2O_5:	Rs 15.11/kg
K_2O:	Rs 11.12/kg
S:	Rs 3.56/kg
Micronutrients	
Zinc:	Rs 500/t
Boron:	Rs 300/t

(Rs 100= $ 1.40)

Source: Indian Govt Dept of Fertilizers

The market price of phosphate, potash and NPK fertilizers went up heavily following the introduction of the NBS. Consequently, as farmers started applying cheaper urea at the expense of needed phosphate and potash products, unbalanced fertilization has prompted a further deterioration in agricultural productivity. As well as imposing financial losses on farmers, the above situation also inflicts a heavy burden on the environment, as the leaching of excess nutrients degrades water and air.

Until 2018, subsidies were directly paid to fertilizer producers based on the volumes placed on the market. This unfortunately resulted in examples of large scale manipulation of the subsidy payment system. The government therefore decided to devise and implement a new of subsidy payment system – the direct benefit transfer (DBT) system – based on actual purchases by farmers. This was designed to prevent potentially fraudulent leakages within the system.

As a first step, fertilizer sales are currently being recorded at the retail level through point-of-sale devices. Subsidies based on actual sales are then transferred to the manufacturer on a weekly basis. The ultimate success of the DBT system will be judged on its ability to guarantee the direct transfer of subsidies to the bank accounts of farmers. Eventually, a more efficient subsidy payment system in India will have the dual benefit of guaranteeing higher fertilizer usage, as more product will actually arrive on the farm, ultimately allowing lower levels of government support. ■

the world's largest importer of N, P and K combined. This dependency has been aggravated by a lack of a co-ordinated programme for expanding domestic fertilizer production, and the prevalence of ad-hoc policies within the farming and fertilizer sector. Subsidising the fertilizer market also places a massive fiscal burden on the government, distorting both the market and detracting from other pressing investment priorities.

The Indian government, responding to increasing fertilizer consumption and rising imports, with attendant large outgoings in foreign exchange, has adopted a three-pronged approach to address the situation. This involves:

- Production units entering into long-term supply contracts with foreign suppliers
- Pursuing further joint ventures with overseas producers, and
- Encouraging Indian companies to buy out fertilizer assets abroad.

Additionally, the government has acknowledged that existing policy measures were not attracting private investment in new urea plants. It therefore embarked on a programme of reviving five old urea plants, all of which had closed for various reasons. By providing new technology and feedstock options, the aim was to bring these plants back into operation, adding 6.35 million tonnes of domestic urea production capacity, at an investment cost of INR 37,871 cr. However, urea imports are set to remain at their current level for at least the next couple of years until these plants become fully operational.

Future outlook

Fertilizer projects are highly capital and energy intensive ventures. There are a range of reasons why domestic fertilizer production in India has lacked a strong growth impetus. The lack of investment incentives, infrastructural bottlenecks, volatility in the fertilizer pricing/subsidy regime, intolerable delays in subsidy payments, the ready availability of competitively-priced fertilizer products on the international market – these have all played a role.

Encouragingly, however, previous experience tells us that a multi-pronged approach can work at overcoming such obstacles. Improvements in crop productivity, through prudent farm support and reductions in farming costs, are certainly required. An assured grain price together with slow, timely and affordable rises in fertilizer costs – an issue linked to optimising domestic production costs – plus quicker release of subsidy payments are also priorities. Collectively, these measures hold the key to a prosperous and sustainable future for Indian agriculture and Indian farmers. They should also help free India's fertilizer industry from its present travails and turmoil – as well as easing government fiscal pressures to a certain extent. ■

About the author

Dr MP Sukumaran Nair is an acknowledged Indian fertilizer industry and policy expert. He was formerly special secretary to the chief minister & chairman of the government of Kerala's public sector restructuring & audit board.

Planted out rice seedlings in a paddy field.

PHOTO: ZVONIMIR ATLETIC/SHUTTERSTOCK.COM

Rice fertilization

Rice is one of the world's most popular food staples, providing around one-fifth of the total global calorific value of human diets. Cultivation and consumption is particularly prevalent in Asian countries. We look at the nutrient needs of this widely-grown cereal.

Rice (*Oryza sativa*) is the primary food staple for more than half of the world's population. More than 3.5 billion people depend on rice for more than 20 percent of their calorific intake – with Asia, South America and sub-Saharan Africa being the largest rice-consuming regions globally.

Rice can be grown in a wide range of latitudes and under many different soil, climate, and hydrological conditions. But it is mainly grown in the humid and sub-humid climates of tropical and sub-tropical regions.

World production

World production of milled rice more than tripled between 1960/61 and 2017/18, increasing from 151 million tonnes to 495 million tonnes. (The equivalent rough rice tonnages rose similarly, from 221 million tonnes to 740 million tonnes.) These increases have been delivered largely through yield improvements – the global average rice yield having more than doubled from just 1.8 t/a in 1960/61 to 4.6

IMAGE: ANNALISA E MARINA DURANTE/SHUTTERSTOCK.COM

Typical rice plant (*Oryza sativa*).

RICE: Key facts

- Rice is the world's second largest staple crop behind corn (maize).
- It is grown and produced on a vast scale, with a total of 740 million tonnes (495 million tonnes milled) harvested in 2017/18 from an area of 163 million hectares.
- Four major types of rice are grown worldwide.
- *Indica*, the most common type – being responsible for 75 percent of global production – is grown in the tropics and sub-tropics of India, Central and Southern China, and the Philippines.
- Aromatic rice (Jasmine and Basmati) accounts for 15 percent of global production and is mainly grown in Northwest India and Pakistan.
- *Japonica* (8% global production) originates from Northern and Eastern China and is grown extensively in cooler sub-tropical and temperate zones.
- Glutinous rice (<2% global production) is grown mainly in Southeast and East Asia.
- Rice production underwent significant growth during the middle 20th century as part of the 'Green Revolution' in Asian agriculture.
- The decades between the 1930s and the late 1960s saw major advances in agricultural inputs and practices – such as the introduction of improved, high-yielding, disease-resistant seeds, more extensive irrigation, wider fertilizer and pesticide use, and the shift to mechanisation.

RICE MARKET MONITOR

Global rice production at 512 million tonnes was largely unchanged in 2019, according to the latest assessment from the UN FAO. This production volume is down just half of one percent from 2018's all-time record high. On the consumption side, world rice utilisation for 2019/20 looks likely to rise by one percent year-on-year to a record high of 514 million tonnes. This is despite a 1.3 million tonne downward revision in March.[2]

World rice stocks at the close of 2019/20 were recently revised upwards to 182 million tonnes, marginally below their record opening levels. Lower closing stocks in Thailand have been outweighed by higher than anticipated reserves in India. Record-breaking public sector carry-ins and local procurement suggests India will account for much of the foreseen rise in export inventories in 2019/20[2].

World rice trade this year (January-December 2020) is forecast to recover by 3.6 percent year-on-year to reach 46 million tonnes. Higher exports from India and mainland China underpin much of the predicted recovery[2]. ■

t/ha by 2017/18 – while world harvested area increased by just over one-third over this period, from 120 million hectares to 163 million hectares. Global production and yields have continued to grow modestly over the last decade (Figure 1).

Five countries – China, India, Indonesia, Bangladesh and Vietnam – account for more than 70 percent of global production and consumption (Figure 2). Of these, China and India alone are responsible for more than half of global rice production and consumption. Rice provides up to half of dietary calories for hundreds of millions of people in Asia – and is therefore vital for food security. Rice has also emerged as the fastest growing food staple in sub-Saharan Africa[1].

Cultivation practices

Rice is unique among cereal crops because its root system is adapted to flooded and largely anaerobic soil conditions. Rice crops are grown in four main environments:

- Irrigated systems
- Rainfed lowland areas
- Rainfed upland areas
- Flood-prone deepwater environments.

Irrigated rice is grown in bunded fields known as paddies. These are surrounded by a small embankment that keeps the water in. This productive growing practice delivers 75 percent of world rice production while covering some 54 percent of the world's harvested area for rice[1].

Cultivation in rainfed lowland areas provides a further 20 percent of the global rice harvest, with rice grown in rainfed upland areas contributing an additional four percent to the world total. Deepwater rice is grown in flooded conditions in which the water depth is more than half a metre for at least one month of the year. Although it contributes just one percent to the global rice harvest, more than 100 million people in South and Southeast Asia rely on deepwater rice for their sustenance[1].

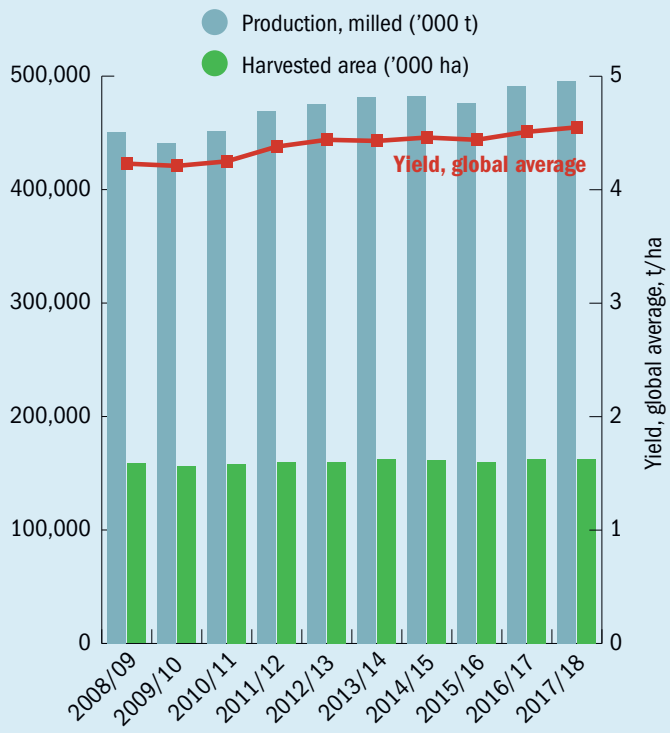
Fertilizers account for 20-25 percent of total production costs in lowland rice systems. Therefore, increasing rice yields by adopting suitable nutrient management practices has become an essential part of modern rice cultivation.

Plant growth and yield

The traditional method for cultivating rice is in paddy fields. These are flooding to a depth of 5-25 cm during or after the placement of young seedlings. This simple method, although requiring the channelling and damming of water, reduces the growth of weeds and deters rodents and pests.

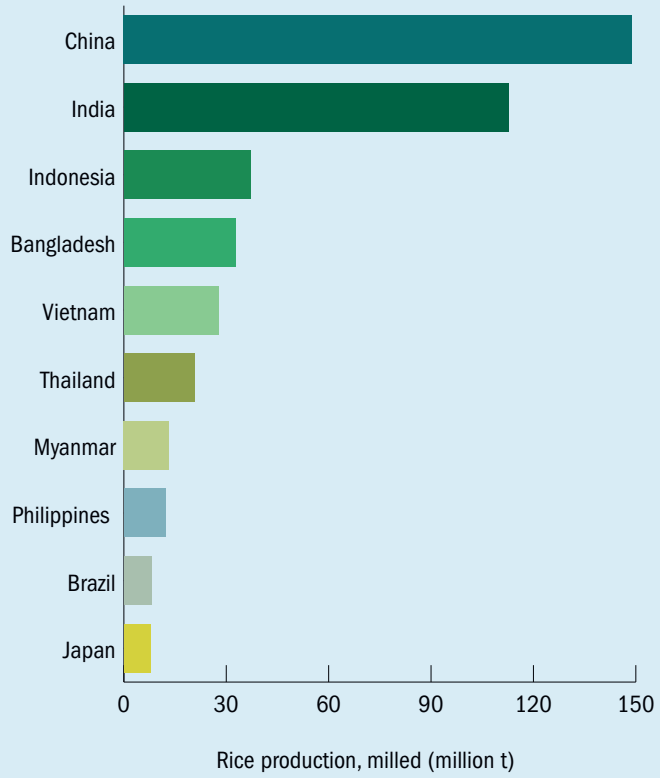
Rice plants grow a main stem and four or five side stems known as **tillers**.

Fig. 1: **Global rice production, harvested area and average yield, 2008/9-2017/18**



Source: USDA

Fig. 2: **The world's top 10 rice producing countries, 2017/18**



Primary tillers grow from the lowermost nodes of the transplanted seedlings with further secondary and tertiary tillers emerging from higher nodes as the stem grows. Each tiller grows a flowering head known as a panicle. It is the **panicle** that ultimately produces harvested rice grains[3].

Rice seedlings grow rapidly, taking 4-5 months to reach maturity with plants eventually growing to a height of 90 cm. By late summer, rice grains begin to appear in long panicles on the top of the plant. By the end of summer, these grain heads are mature and ready to be harvested[3].

Fertilizer application rates and timings are critical to successful rice cultivation. High-yielding modern rice cultivars are highly dependent on the supply of essential nutrients in adequate amounts[4].

Rice typically requires 14.7 kg N, 2.6 kg P and 14.5 kg potassium per tonne of grain yield. Nitrogen and potassium supply is particularly critical when panicles start to emerge – typically about 60 days before harvest for tropical rice. Insufficient nitrogen at this growth stage reduces the number of spikelets per panicle, resulting in a loss of yield. Inadequate K supply at this stage also negatively influences yield by affecting both grain filling and the number of panicle spikelets[3].

The global average yield of irrigated rice is 5 t/ha, although yield averages vary widely – nationally, regionally, and seasonally. Skilled rice farmers in the tropics can achieve rice yields of 7-8 t/ha in the dry season and 5-6 t/ha in the wet season. The productivity of rainfed upland and deepwater rice is much lower at around 1 t/ha[4].

This article mainly focusses on rice fertilization in irrigated and rainfed lowland systems – as these account for about 92 percent of total rice production and 80 percent of the global harvested area.

The cultivation of rice under flooded soil conditions affects nutrient availability, uptake, use efficiency and fertilization practices. Average N, P, and K nutrient use efficiency for rice cultivation in five key growing countries was estimated at just 33 percent, 24 percent, and 38 percent, respectively. These use efficiencies were based on field trials with 179 farmers in China, India, Vietnam, Indonesia and the Philippines. Nevertheless, the understanding of nutrient management in lowland rice has progressed rapidly in recent decades, although further research is required[4].

Rice deficiency symptoms

Deficiency symptoms vary according to the mobility of the nutrient within the plant. For mobile nutrients (nitrogen, phosphorus, potassium and magnesium), deficiency symptoms appear in oldest (lower) leaves first. This is because mobile nutrients tend to migrate to the youngest leaves which act as sinks. In contrast, deficiency symptoms for immobile nutrients (calcium, iron, manganese, zinc and sulphur) appear in youngest (upper) leaves first because these nutrients are locked within the oldest leaves and parts of the plant[3].

Nitrogen for yield capacity

Nitrogen is generally the most yield limiting nutrient in rice production[4] as it is associated with:

- Plant height
- Panicle numbers
- Leaf size
- Spikelet numbers
- The number of filled spikelets – this largely determines the yield capacity of the rice plant.

Modern high yielding rice varieties, which typically produce around 5 t/ha of grain, can remove about 110 kg of nitrogen from the soil[4]. Prolonged nitrogen deficiency causes severe plant stunting, reduces tillering and depresses yield[3].

Nitrogen is applied to rice in split applications. The number of applications and overall application rate can be adjusted to meet nitrogen demand. This is generally estimated using leaf colour charts[3].

In water-seeded rice, where the soil is flooded for periods during the growing season, most of the nitrogen fertilizer is generally applied pre-planting and prior to flooding. At this stage, around 65-100 percent of the total nitrogen application is typically applied, as an ammonium (NH_4^+) fertilizer source, usually when rice plants are at the 4-5-leaf growth stage.

Nitrogen fertilizers placed on dry soil need to be flooded-in immediately, or shallow incorporated and then flooded within 3-5 day. Incorporation will protect against ammonia volatilisation and nitrification/denitrification losses as long as the flood is maintained. Soils need to remain flooded for at least three weeks to maximise the uptake of early applied nitrogen[3].

Sufficient nitrogen should be applied at the pre-planting stage to ensure no additional nitrogen is needed by rice plants until the panicles start to emerge. Additional nitrogen should be topdressed at this stage, or when nitrogen deficiency symptoms appear[3].

The application of nitrogen to irrigated lowland rice can be very inefficient, however. Nitrogen use efficiency generally varies between 20-80 percent with an average of about 30-40 percent[4].

To improve fertilizer efficiency, the International Rice Research Institute (IRRI) has developed a site-specific nutrient management (SSNM) approach for rice fertilization. IRRI suggest that rice crops requires about 50 kg/ha of nitrogen fertilizer for each tonne of additional grain yield. Using this relationship, optimum nitrogen application rates can be calculated using target rice yields of 5.5 t/ha in the dry season and 6.5 t/ha in the wet season. SSNM recommends applying nitrogen as three split applications, with an early application of about 20-30 percent of the total requirement. The remaining 70-80 percent is split between two subsequent applications, based on demands of the rice crop, as determined from leaf colour using leaf colour charts[3].

Phosphorus for roots, flowering and ripening

Phosphorus supply is critical for maximising rice grain yields. It is particularly important during early vegetative growth stages because of its role in tillering, root development, early flowering, and ripening. Early application is essential for root elongation[3].

Phosphorus-deficient plants are stunted, have abnormal bluish green foliage, erect leaves, relatively few tillers and poor root mass. Development of the canopy is also slowed and plant maturity delayed. Plant tissue testing is the best tool for diagnosing deficiency[3].

Above-ground phosphorus uptake by high-yielding rice varieties may approach 60 kg/ha, but more commonly lies in the range 25-50 kg/ha. Some 60-75 percent of total plant phosphorus resides in the panicles at maturity[4].

Phosphorus fertilizers are typically soil-applied when the land is being prepared pre-planting or pre-flooding. Recommendations are usually made on the basis of soil tests levels and yield expectations.

For flooded rice in Asia, phosphorus is normally applied at a rate of 26 kg/ha to maximise yields, while in the United States between 10-40 kg/ha is applied. At the extreme end, soils with high P-fixing capacities may require applications as high as 97-175 kg/ha[4].

Highly water-soluble single and triple-super phosphates (SSP/TSP), diammonium phosphate (DAP), and sometimes monoammonium phosphate (MAP), are the phosphate fertilizers most commonly applied to rice[4].

Potassium for grain number and weight

Potassium improves root growth and plant vigour, helps prevent lodging, and enhances crop resistance to pests and diseases.

In high yielding rice systems, potassium is often the most limiting nutrient after nitrogen[4] as it promotes:

- Tillering
- Panicle development
- Spikelet fertility
- Uptake of nitrogen and phosphorus
- Leaf area and leaf longevity
- Disease and pest resistance
- Root elongation and thickness
- Stem thickness and strength
- Resistance to lodging.

Potassium plays a particularly valuable role in improving grain number and grain weight due to its influence on photosynthesis and other plant functions[3].

Modern high-yielding rice varieties take-up potassium in larger amounts than any other major nutrient. In Asia, for rice crops yielding 5 t/ha, total potassium uptake is around 100 kg/ha – although this is concentrated in the straw at maturity, not the harvested crop. Total plant potassium uptake may even exceed 200 kg/ha for rice yields greater than 8 t/ha[3].

Potassium recommendations are usually based on soil test results. An application of 50 kg/ha is normally applied to maximise flooded rice yields. Straw needs to be factored in as an important additional nutrient source when calculating K requirements, given that 80 percent of potassium remains in the straw after harvest[4].

Applying potassium after deficiency symptoms appear can be relatively ineffective, as these generally deliver only limited yield improvements[3].

Major deficiencies and their correction

Inadequate nutrient supply is a major yield-limiting factor in rice cultivation. Phosphorus, zinc or iron deficiencies – or the presence of excess of salts like iron or aluminium – affect rice yields over about 50 million hectares of rice land in Asia[4].

Micronutrient deficiencies are mainly associated with silty and sandy loams and other high pH soils (>7.5), but do not generally occur in acid and slightly-acid clay soils (pH = 5-6.5[3]).

> **Fertilizer applications and timings are critical for successful rice cultivation.**

Zinc deficiency is associated with low organic matter soils with high levels of available phosphorus. Waterlogged soils are also particularly susceptible. Deficiency in rice after transplanting is a widespread phenomenon limiting productivity in lowland growing conditions. Rice yield losses due to Zn deficiency can range from 10-60 percent. Inadequate soil zinc levels limit tillering in rice and, consequently, the number of panicles[4].

Broadcasting zinc sulphate (10-25 kg/ha of $ZnSO_4 \cdot H_2O$ or 20-40 kg/ha of $ZnSO_4 \cdot 7H_2O$) over the soil surface is recommended when deficiency symptoms are observed. Foliar sprays of zinc sulphate solution (200L of 0.5% solution per hectare) are an effective emergency treatment for Zn deficiency in growing plants[4].

Sulphur deficiency is also widespread in many rice-growing regions, including India, Brazil and Southeast Asia, affecting both the number of panicles and panicle length. Sulphur applied at a rate of least 10 g/ha is reportedly necessary, with ammonium sulphate and single superphosphate being good sources. Up to 20-40 kg/ha of sulphur can be applied on severely deficient soils[4].

Gypsum is also widely-applied as both a sulphur (sulphate) and calcium source. However, calcium deficiency in rice usually signals unfavourable growing conditions, rather than inadequate supply to the roots. Deficiencies can develop due to waterlogging, soil salinity and root disease, for example, or because of excess potassium or ammonium supply. Deficiencies are relatively rare in irrigated rice systems but are common in leached acid soils in both upland and lowland areas[3].

Calcium plays an important role in cell wall strength and the functioning of cell membranes. Deficiencies occur in the youngest leaves and growing points.

Boron deficiency typically causes floret sterility, resulting in reduced grain yields in rice. The panicles in boron-deficient rice plants can also fail to emerge from the boot. Deficiency can be corrected by applying soluble boron sources – such as borax – typically supplying B at a rate of 0.5-3 kg/ha. Borax can be broadcast and incorporated before planting, top-dressed, or applied as a foliar spray[4].

Iron deficiency commonly occurs in rainfed dry nurseries, or when rice is grown under upland conditions. Rice seedlings are most susceptible before flooding. Iron deficiency is best treated by applying iron sulphate ($FeSO_4$ supplying Fe at a rate of 30 kg/ha) next to rice rows. Iron sulphate can also be broadcast alongside crop residues, green manures, or animal manures. Foliar applications (solution of 2-3% $FeSO_4$ or Fe chelates) can also cure deficiencies[4].

Manganese deficiency is observed in:

- Upland rice
- Alkaline and calcareous soils with low organic matter status
- Degraded paddy soils high in Fe
- Acid uplands (oxisols, ultisols)
- Leached acid sulphate soils
- Leached sandy soils
- Excessively limed acid soils.

Deficiency can be corrected by foliar applications ($MnSO_4$ solution) – or by applying manganese (5-20 kg/ha as sulphate or oxide) in bands along rice rows with an acidifying starter fertilizer such as ammonium sulphate[4].

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Drip irrigation

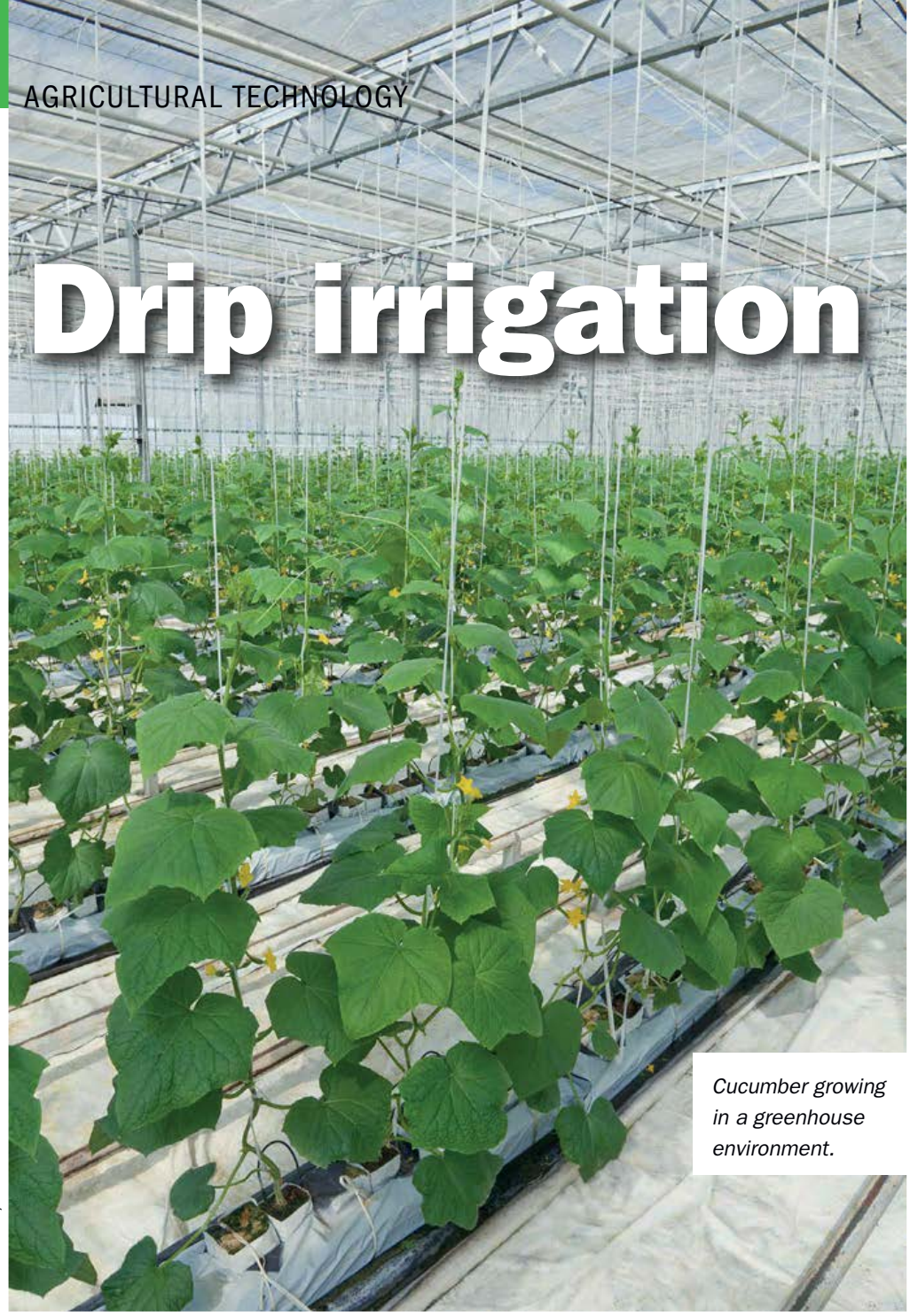


PHOTO: BORK/SHUTTERSTOCK.COM

Cucumber growing in a greenhouse environment.

With more than 15 million hectares of land watered by drip irrigation globally, the technology's agricultural potential remains enormous. Fertigation – the ability to manage and regulate both water and plant nutrients – is a key advantage helping drive worldwide growth.

In June 2012, David Hillel, an Israeli scientist who pioneered an innovative way of efficiently delivering water to crops in arid and semi-arid regions, was awarded the World Food Prize. The method Hillel helped develop, drip irrigation, supplies water directly to plant roots in small amounts – dramatically cutting crop water requirements and at the same time boosting crop yields.

The development of drip irrigation is arguably one of the most important agricultural advances of the last 50 years. Although more than 15 million hectares of land is watered by drip irrigation globally, the technology's agricultural potential, and its use as a vehicle for delivering water-soluble fertilizers, is still in its infancy.

Double-digit growth

The thriving commercial market for drip irrigation equipment, currently worth $4.9 billion, is expected to grow by around 10 percent annually to reach $8.5 billion by 2025. The rising popularity of drip irrigation is linked to the need for water efficiency in drought-prone regions, and is also being boosted by government support programmes and subsidies. The ability to efficiently manage and regulate both water and plant nutrients is another key advantage that is helping drive worldwide growth in drip irrigation.

Drip irrigation has long proved profitable for watering vegetables and perennial orchard crops, and also has a strong foothold in the turf & lawn market. The technology is now finding increasing favour in the cultivation of field crops too – particularly corn, sugarcane, and cotton. Its ability to precisely deliver inputs to field crops in the correct amounts helps reduce costs and improve profit margins by lowering both water and fertilizer requirements. China and India are two key markets being targeted by drip irrigation manufacturers due to their large agriculture sectors.

Drip irrigation

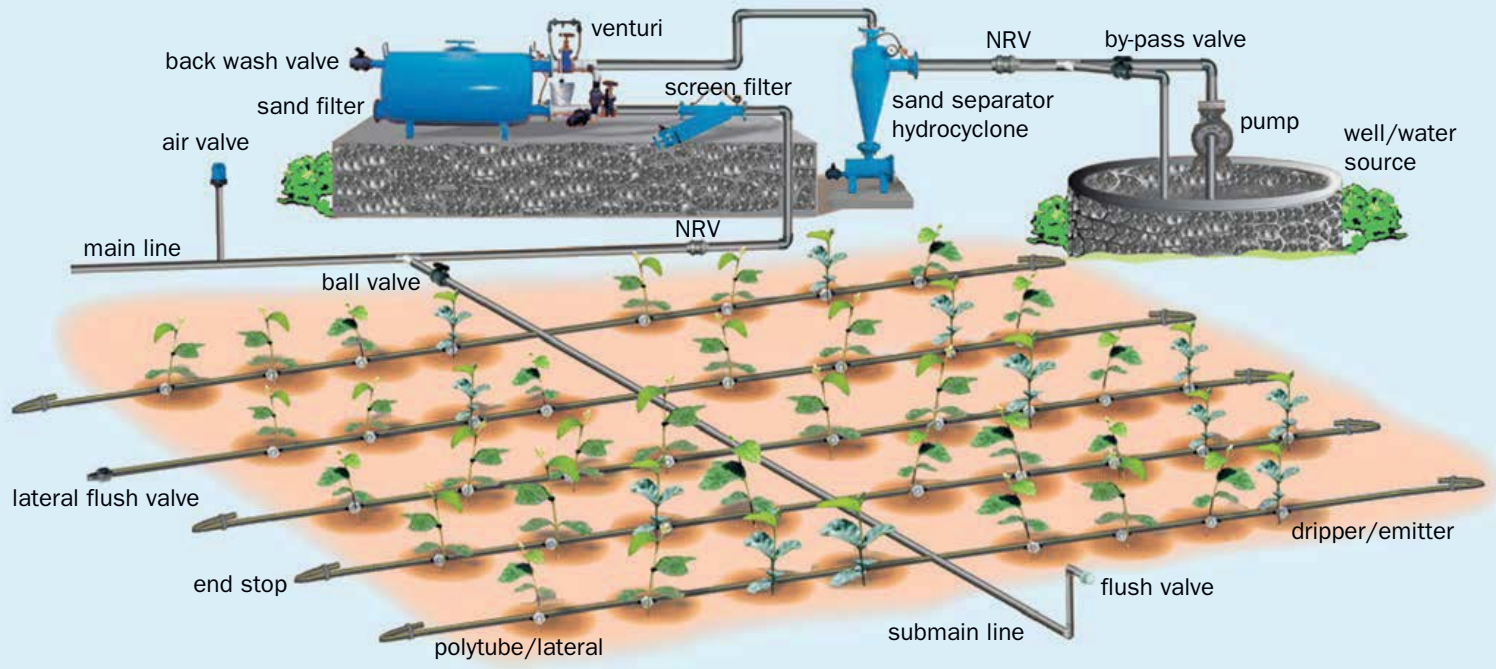
Most farmers still irrigate their fields by flooding or watering the furrows between crop rows. Unfortunately, less than half the irrigation water applied to fields in this way actually benefits crops. The excess water is not necessarily lost, as some it will return to rivers or groundwater sources to be used again. Nevertheless, unnecessary abstraction of water for irrigation purposes can deplete freshwater supplies and result in evaporation.

Drip irrigation, originally invented and developed by Simcha Blass and his son Yeshayahu in Israel in the late 1950s, is one of the most significant advances in modern agriculture. Due to its water- and fertilizer-saving abilities, drip irrigation – also known as micro-irrigation, trickle irrigation or localised irrigation – has since become an increasingly common irrigation method for growing crops in greenhouses and fields.

In drip irrigation, drops of water are supplied at or below the surface, close to plants at very low rates (2-20 litres/hour) via a pressurised system of small diameter plastic pipes connected to outlets called emitters or drippers. Enough water is applied at regular intervals, usually every 1-3 days, to wet the root zone and provide the favourable high moisture conditions plants need to flourish.

Drip irrigation is more efficient than other methods which saturate the whole soil profile, such as surface and sprinkler irrigation, reducing weed growth and the leaching of plant nutrients. The drip irrigation of 100-200 plants typically consumes 40-80 litres per day. In arid and semi-arid regions, particularly in Israel and around

Fig. 1: **Schematic of a drip irrigation system**



Source: Jain Irrigation

the Mediterranean, recycled wastewater is often used to supply drip irrigation.

Drip irrigation systems are suitable for commercial crops grown in rows, including vines, vegetables, soft fruits bushes and fruit trees, with one or more emitters allocated to each plant. Installation is generally only economic for high-value crops due to the capital costs involved.

A typical drip irrigation system (Figure 1) is made up of the following components:

- **Pump unit**: this delivers water from the source to the pipe system under pressure.
- **Control head**: this uses valves to control the system's flow rate and pressure and may also contain screen filters and sand filters to clear the water by removing finely-suspended matter. Some control head units are fitted with a nutrient tank for fertigation. This allows fertilizers to be added to water in measured doses – one of the major advantages of drip irrigation.
- **Mainlines, submain lines and laterals**: these pipes distribute water from the control head to the field. They are usually made from PVC or PE plastic hosing and are often buried to prevent degradation from the sun. Lateral pipes are usually 13-32 mm in diameter.
- **Emitters (drippers)**: these devices control the release of water to plants. They are usually spaced along laterals at more than a metre apart. One or more emitters are typically used for a single plant such as a tree, although they are generally more closely spaced when used for row crops. Emitters are designed not to block easily and should discharge water at a constant flow even when the pressure varies.

Drip irrigation systems require regular upkeep to maintain their efficiency. Leaks may develop due to pipe damage, for example, and emitters can also become blocked, even with filtered water. The build-up of salinity also needs to be monitored carefully, as salt can accumulate in soil along the edge of the wetting front. Additional irrigation may be also necessary during crop establishment as wetting from drip systems may not be enough to trigger seed germination.

On sloping land, drip irrigation laterals are generally placed in parallel with crop rows planted along contour lines. This minimises any potential variation in emitter discharge due to land elevation. Water needs to be applied slowly during the drip irrigation of clay soils to avoid ponding and run-off. Higher emitter discharges are used on sandy soils to ensure wetting is sufficient.

Because drip irrigation saturates a relatively small volume of soil, plants develop their roots in a small localised zone nearest to the water emitter. This limited root system is not problematic as long as favourable soil conditions are maintained, particularly low salinity and adequate aeration.

Inexorable rise

Drip irrigation was adopted agriculturally on a large-scale during the 1970s for fruit and vegetable production in Australia, Israel, Mexico, New Zealand, South Africa and the US. Compared to conventional flood or furrow irrigation, drip irrigation has the potential to reduce water use by up to 70 percent and at the same time increase crop yields by 20-90 percent.

The global area covered by drip irrigation systems has risen more than fivefold in the last 20-25 years, rising from three million hectares in 1996 to 16 million hectares currently (Figure 2), based on the latest figures published by the International Commission on Irrigation and Drainage (ICID).

The most dramatic expansions have occurred in two of the world's top irrigators, China and India, where the area under drip irrigation has grown exponentially over the last two decades. The area cultivated under drip irrigation has accelerated particularly quickly in China and currently stands above five million hectares. Three other countries globally, India, Spain, and the US, each have more than 1.5 million hectares devoted to cultivation by drip irrigation. California, due to the concentration of fruit and vegetable growing within the state, accounts for around two-thirds of the area under micro-irrigation in the US, with Florida and Texas coming a distant second and third.

The switch from traditional irrigation methods to drip irrigation makes most economic sense for high-value crops grown in water-scarce regions. The resulting water savings can be considerable. In northwest China, for example, furrow or flood irrigation methods have an annual water demand of 7,320 m^3/ha on average, compared to only 3,250 m^3/ha for drip irrigation[1].

Drip irrigation is used without fertigation in most developing countries, with fertilizer dressings being applied by broadcasting and banding instead. In other countries, particularly Israel, the integration of fertigation has been a key factor behind drip irrigation's rapid adoption. The simultaneous delivery of water and nutrients directly to the root zone is known to be advantageous (see box) for a number crops – tomatoes and other salad vegetables, for example – and also helps minimise nitrate-leaching losses[1].

Drip irrigation has been rolled-out to cover three-quarters of the total land under irrigation in Israel. Its success there is also undoubtedly linked to the fact that the method was originally pioneered in Israel, and because of other factors such as limited water availability.

Bestowing benefits

Drip irrigation is water efficient because it wets the soil sufficiently to satisfy the transpiration demands of plants – yet keeps soil evaporation losses and the deep percolation of water to a minimum. Application efficiencies as high as 0.9 are possible with drip irrigation, compared to 0.6-0.8 for sprinkler systems and 0.5-0.6 for surface irrigation[1].

Switching from flood irrigation to drip irrigation – by enabling crops to be grown on sloping land that was impossible to water previously – has also enabled irrigated land area to double in some regions, sugarcane cultivation in Maharashtra, India, being one notable example[1].

Another advantage of drip irrigation is its ability to balance soil aeration with wetting. During furrow and flood irrigation, in contrast, soils become waterlogged at times, reducing the supply of oxygen to roots. Valuable plant nutrients are also partially removed as excess water drains from the soil.

Installing the drip system beneath the soil surface further reduces evaporation and delivers water and nutrients directly to the root zone. In the Middle East, the switch from furrow irrigation to sub-surface irrigation has doubled wheat yields in some instances[1]. Significant yield and water use efficiency improvements have also been reported for tomato, cotton, alfalfa and cantaloupe.

Much higher water use efficiencies are also obtained in sub-surface irrigation (1.64-3.34 kg grain/m^3) than is possible with furrow irrigation (0.46-1.2 kg grain/m^3). Soil nitrogen release is also much higher under subsoil irrigation (11-216 kg/ha) compared to furrow irrigation (11 to 33 kg/ha).

Markets and companies

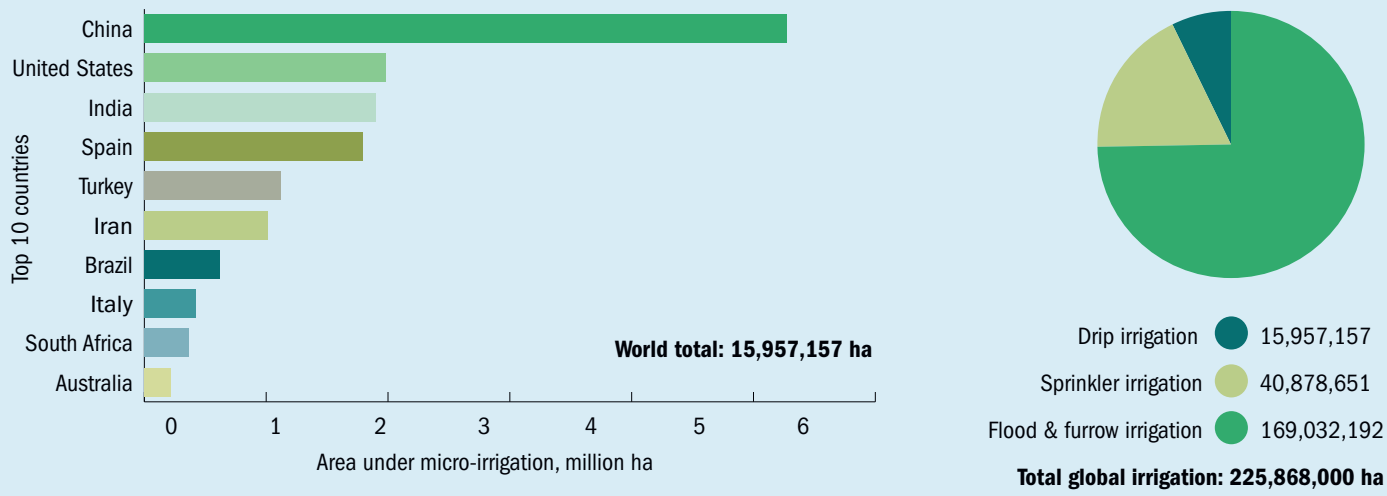
The commercial drip irrigation market globally was valued at around $4.9 billion last year. The US has traditionally been the world's largest market for micro-irrigation systems. But the Asia-Pacific region – India and China in particular – became the largest consumers of drip irrigation equipment in 2019. It is this region that also looks set to dominate market growth over the next five years.

Key global manufacturers of drip irrigation equipment and systems include:

- India's Jain Irrigation Systems Ltd and Mahindra EPC
- Israel's Netafim Ltd, Elgo Irrigation Ltd, Metzer Group and Rivulis
- US-based Lindsay Corp, The Toro Company, Rain Bird Corporation, T-L Irrigation and Dripworks Inc
- China's Chinadrip Irrigation Equipment Co Ltd and Shanghai Huawei Water Saving Irrigation Corp
- Spain's Sistema Azud and Grupo Chamartin (Chamsa)
- Antelco Pty Ltd in Australia and Microjet Irrigation in South Africa.

Four major players, Netafim, The Toro Company, Jain Irrigation Systems Ltd and Rain Bird Corporation, were thought to collectively control more than half of the global market for drip irrigation systems, as of 2016. Rivulis has, however, greatly expanded its global presence by recently opening a massive new equipment production plant in Leon, Mexico. The plant, the largest drip irrigation factory in the Americas, was expected to reach full capacity (the production of half a billion metres of drip line annually) by the end of 2019.

Fig. 2: **Drip irrigation: (a) top ten countries by land area, 2018/19; (b) land area compared to flood & furrow and sprinkler irrigation**



Note: Some country estimates date back to 2004.

Source: ICID Annual Report, 2018/19

Fertigation

Fertigation involves supplying plants with nutrients via a drip irrigation system. It allows nutrients to be applied precisely to crops when they are most needed during the growing season. Tailoring fertilizer use in this way helps to optimise crop yields, cuts input costs by avoiding over application, and also helps to reduce environmental impacts by preventing nutrient leaching and losses.

Protecting fertigation equipment

Fertigation systems are relatively complex and expensive. They can include pumps, backflow prevention systems, filters, nutrient storage tanks, fertigation injectors, timers, drip tubing and emitters. Efficiently delivering nutrients to plants through these systems using water-soluble or liquid fertilizers requires careful management and regular equipment maintenance. This is necessary to ensure fertigation delivers nutrients to plants in a timely efficient manner and to protect investment in fertigation by preventing equipment damage. The clogging of pipes and emitters, in particular, is a major concern.

Quality considerations

Single- or multi-nutrient solutions can be prepared for fertigation by dissolving soluble fertilizers in irrigation water. Fertilizers such as ammonium nitrate, calcium nitrate, monopotassium phosphate, potassium chloride, potassium nitrate, potassium sulphate, urea and urea-phosphate are commonly used[2].

The suitability of fertilizers for fertigation depends on a number of factors. Solubility, solution pH, insoluble content and corrosiveness are all important quality characteristics. Variations in solubility with temperature can also be an issue, as fertilizers which dissolve easily in summer may precipitate out in colder winter conditions[2].

Water quality also has to be taken into account. Irrigation waters can vary in terms of their pH, electrical conductivity (EC) and the concentration of dissolved cations and anions. Fertilizers need to be compatible, both with irrigation water and with the other fertilizers they are mixed with. Incompatibilities can cause solubility changes and the formation of undesirable precipitates and therefore need to be avoided[3].

Among the most popular type of water-soluble fertilizers for fertigation are:

- Monoammonium phosphate (MAP, $NH_4H_2PO_4$)
- Monopotassium phosphate (MKP, KH_2PO_4)
- Magnesium Sulphate ($MgSO_4$)
- Potassium Sulphate (SOP, K_2SO_4)
- Potassium Nitrate (NOP, KNO_3)
- Calcium nitrate ($Ca(NO_3)_2$)

Avoiding clogging

For fertigation, irrigation water and fertilizer solutions should ideally be slightly acid and kept within the range pH 5.5-7.0. If pH is too high, calcium and magnesium phosphates or carbonates may precipitate in irrigation lines. The plant availability of certain nutrients (P, Zn and Fe) may also be reduced. In contrast, too low a pH is detrimental to roots and may mobilise aluminium and manganese in the soil[4].

Nitric acid (HNO_3) or phosphoric acid (H_3PO_4) are generally used to lower pH levels in fertigation. As well as reducing clogging by dissolving precipitates, they also supply phosphorus and nitrogen to plants. Nitric acid can also help minimise saline injury to plants by reducing chloride salinity in the root zone in saline waters and calcareous soils[4].

The global leader

Netafim, the global market leader in drip irrigation, celebrated its 50th anniversary in 2015. The firm has 28 subsidiaries, operates 16 manufacturing plants and employs more than 4,000 employees worldwide, enabling it to deliver systems and components to some two million customers in 110 countries.

In 2014, Netafim's Indian subsidiary won a $62 million contract with state-owned Krishna Bhagya Jala Nigam Ltd for reportedly the world's largest micro-irrigation project in the southern state of Karnataka. This involved Netafim building an automated drip irrigation network covering 11,800 hectares of land cultivated by around 6,000 farmers in the Bagalkot area of Karnataka.

The government-owned Ethiopian Sugar Corporation awarded Netafim the world's biggest sugarcane drip irrigation project in 2015. Designed to boost the country's domestic sugar production, the 7,000 hectare project – based at the Wolkaite sugarcane plantation – is fed by a 65-kilometre water pipeline and required the installation of a staggering 40 million metres of driplines.

Also in 2015, Netafim signed a $17 million contract with Vingroup, a major Vietnamese food retailer, for a 30 hectare greenhouse project, one of the largest in Southeast Asia. Netafim was contracted to supply greenhouses, drip irrigation and climate control systems, and agronomic services as part of the deal. This project has enabled Vingroup to directly supply its supermarkets with high-quality, domestically-produced melons and leafy greens, 365 days a year.

The installation of a Netafim sub-surface drip system in the Philippines has also increased sugar cane yields by 90 percent, compared with a conventional centre-pivot sprinkler system, and cut water consumption by 70 percent – a huge increase in water productivity. The sucrose content of the sugarcane crop was also boosted by five percent, according to Netafim.

Other notable Netafim projects include:

- **Azerbaijan:** Five hectare tomato-growing polyhouse project for GP Alpha. The project's precision irrigation system uses renewable energy and water sources to produce high yielding and high quality tomatoes all year round – while consuming 40 percent less water and fertilizers, compared to conventional growing practices.
- **South Africa:** Four hectare polyhouse project for soilless cultivation of blueberries. The Netafim-designed advanced precision irrigation and fertigation system delivers premium quality fruit at a yield of around 28 t/ha.
- **Kazakhstan:** Two hectare glasshouse project for Atyrau Sauda in the country's frozen Atyrau region. This produces

110,000 tonnes of cucumbers, tomatoes and other fresh vegetables throughout the year.

Additionally, Netafim has expanded the use of drip irrigation for cotton cultivation globally, notably in Australia, Egypt, Israel and the US.

Indian market giant

Jain Irrigation Systems Limited (JISL) is India's largest and the world's second largest micro-irrigation company. The company manufactures drip irrigation systems and components at a plant at Jalgaon. These are targeted at farmers growing apples, grapes, banana, sugarcane, tea, coffee, cotton, mango, teakwood, vegetables and flowers. According to Jain, drip irrigation typically cuts water use by 70 percent compared to flood irrigation – allowing more land to be irrigated – and also increases fertilizer use efficiency by 30 percent. The company has grown dramatically in the past 20 years, expanding twenty-fold between 2003 and 2010, and continues to grow strongly today.

10.3 million hectares of India's cropland is currently equipped with micro-irrigation systems, according to the country's ministry of agriculture. This represents just 15 percent of the 79.8 million hectares of Indian agricultural land that could potentially be micro-irrigated. To encourage adoption, the Indian government currently subsidises the installation of both drip and sprinkler irrigation systems by around 50-80 percent, depending on the state and the project concerned.

Jain, which has more than a 50 percent share of the Indian micro-irrigation market, should be well-placed to take advantage of future domestic growth opportunities. The company's hi-tech business unit – which includes micro-irrigation – is a key earner, accounting for more than half of company revenues. Sector earnings are highly dependent on state support, however, as around 46 percent of micro-irrigation revenues last year came from government turnkey projects.

However, debt worries have seen Jain's share price collapse by more than two-thirds over the last 18 months. The company is currently weighing-up the options for paying down debt and restoring investor confidence, including the potential divestment of its overseas micro-irrigation assets.

Nevertheless, Jain's market position is bolstered by a strong project pipeline. For example, the company recently received a letter of intent from the government of Madhya Pradesh to execute the INR 9.8 billion ($137 million) Mohanpura micro-irrigation project. This pressurised pipe project aims to bring more than 92,400 hectares of land under micro-irrigation within a scheduled 36 month period.

Jain is also executing an integrated INR 2.4 billion ($33 million) drip irrigation project in the Wardha district of Maharashtra in India's Vidarbha region. Some 65 villages in Arvi Taluka and more than 10,000 farmers should benefit from the 8,400 hectare project. The project, which is scheduled to be completed within 24 months, uses a pressurised piped network to distribute water from canals to on-farm micro-irrigation systems. This is expected to improve agricultural water use efficiency in the district from 35 percent currently to up to 90 percent.

Jain has also received an $18 million export order from the Rwandan government for a 1,752 hectare irrigation and watershed development project. This is being financed by EXIM Bank of India. Jain is responsible for designing, providing equipment and constructing the project's gravity-fed irrigation systems. These include a mix of sprinkler irrigation, centre pivot and pipe hydrant systems. Jain says it plans to complete the project in the next 18 months.

Jain strengthened its presence in the US market in 2015 by buying PureSense Environmental Inc, a Californian irrigation management and field monitoring technology company.

Jain has also championed solar powered drip irrigation systems for off-grid farming in recent years. It has been working with Harvard University since 2013 on a solar irrigation project for village rice farmers in Bihar. In September 2016, the firm also won a €18.7 million Eritrean government contract to supply and install solar photovoltaic drip systems at 14 different locations in Eritrea. The project, which was due to take around 18 months to complete, should benefit 2,000 small-scale African farmers.

Rice is a notoriously water-hungry crop. So it is unsurprising that Jain is targeting the 43.8 million hectares under cultivation in India. Almost 85 percent of the fresh water consumption in India is for agriculture, much of which, some 70 percent, is used in paddy cultivation.

Trial results have been encouraging. Drip irrigated fields in Tamil Nadu consumed two-thirds less water to yield 22 percent more rice per hectare, in comparison to conventional paddy growing. The switch from paddy growing to drip irrigation by a commercial rice grower in Rajasthan increased crop yield by 25 percent and reduced water and electricity consumption by 40 percent each. The water saved enabled this farmer to expand the area of rice under cultivation from 2.8 to 4.8 hectares.

Untapped potential

Drip irrigation's agricultural potential, and its use as a vehicle for fertigation, is still in its infancy, as Rabobank makes clear: "Only 40-45% of existing irrigation systems possess water-saving technologies… such as micro-irrigation… Water-saving irrigation systems can also help improve the efficiency of fertilizers and agrochemicals."

Although the majority of irrigated crops still use surface or sprinkler methods (Figure 2), drip irrigation will continue to replace surface irrigation on farms where the water supply is costly and/or limited due to low rainfall, drought or other reasons. Drip irrigation can also be economic in situations where farmers have to compete with urban users for their water supply – as improvements in crop yield and quality can more than offset the equipment costs involved.

The wish to conserve water and reduce labour costs have often been the main motivations for switching to drip irrigation in the past. But the economic gains from better crop yields and quality – and more efficient fertilizer use – look like becoming increasingly important deciding factors in future. ■

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Foam Hydrofilter cleans up

Russia's urea research & design institute, NIIK, introduces the *Foam Hydrofilter* – a completely new type of wet scrubber for air pollution control at urea plants. The *Hydrofilter* offers the same operational efficiency as many conventional scrubbing systems while avoiding many of their drawbacks.

Foam Hydrofilter in close up.

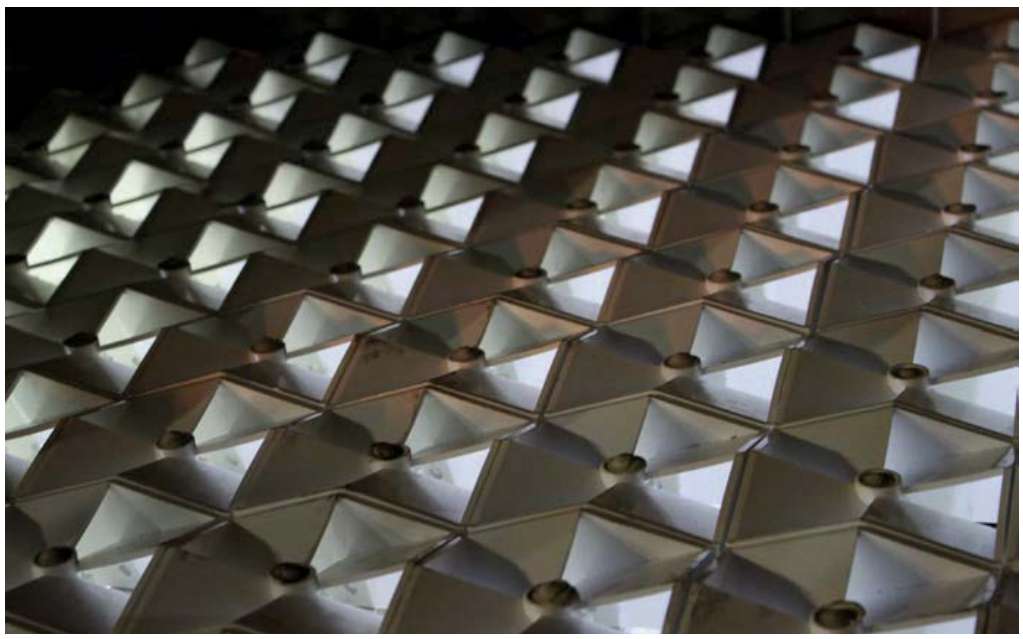


Fig. 1: Foam Hydrofilter's dispersion grating.

Background

For the fertilizer industry nowadays, the control of air pollution during urea production is a particular challenge because of the significant potential health and environment impacts. The need to pay special attention to this issue and prioritise pollution treatment is therefore well understood. Achieving the lowest possible dust emissions at a urea production plant requires the installation of the most practical and effective wet scrubbing system.

Innovative wet scrubbing technology

The *Foam Hydrofilter* (see photo) designed and manufactured by NIIK is a completely new type of wet scrubber. Crucially, it avoids many of the drawbacks of conventional systems yet operates at the same efficiency.

The key to the high performance of the *Foam Hydrofilter* is the special design of its dispersion grating. A flow of gas contaminated with dust/aerosols passes upwards through the dispersion grating and meets irrigated liquid cascading downwards from the top of the scrubber. The gas and the liquid mix to form a 'foam' – a turbulent dispersed gas-liquid layer. This foam layer achieves high scrubbing efficiency by ensuring a high rate of wetting or dissolution of dust particles in the irrigation liquid. Before leaving the *Foam Hydrofilter*, the purified air passes through separators which remove fine droplets of liquid.

Dispersion grating design

The scrubber's dispersion grating (Figure 1) consists of a series of identical elements. Due to the unique geometry of this grating, jets of contaminated gas emerge from holes in these elements at an angle and intersect with one another. The interpenetration of the jets ensures that gas and liquid are mixed over the entire cross-section of the *Foam Hydrofilter* and that liquid is evenly distributed across the grating. This results in the formation of a highly turbulent dispersed gas-liquid layer. This 'foam' is notable for its extremely large specific contact surface, high rate of renewal and homogeneous structure. For a wet scrubber, these design characteristics are highly desirable as they improve air treatment efficiency by significantly increasing both heat and mass transfer

Table 1: **Cleaning efficiency of *Foam Hydrofilter* treatment system installed at EuroChem's Azot urea plant in Novomoskovsk**

Test run	Air consumption	Urea dust concentration at Foam Hydrofilter inlet	Urea dust concentration at Foam Hydrofilter outlet	Cleaning efficiency
No. 1	2,500 m^3/h	8,865.6 mg/m^3	<1 mg/m^3	99.99%
No. 2	2,500 m^3/h	5,677.4 mg/m^3	<1 mg/m^3	99.98%

Source: NIIK

between the contaminated gas and the irrigation liquid.

Competitive advantages

The *Foam Hydrofilter* offers the following advantages over rival wet scrubbing systems:

- A high rate of filtration (99.9% particle removal/cleaning efficiency).
- The technology is designed to scrub a variety of pollutants from gas streams, including dust, vapour and smoke emissions.
- The system is flexible and can be configured for different capacities.
- Equipment design offers long lasting performance and simplicity.
- Quality requirements for the absorption liquid are low.
- The ability to handle a wide range of load capacities.
- Ease of maintenance and operation – virtually no wear and tear, dirt collection or drop entrainment.
- Comparatively low running costs.

Flexible installation is another notable characteristic of the *Foam Hydrofilter* system. It can replace the whole of an existing air scrubbing system, for example, or only certain components can be used (e.g. the dispersion grating and separators) as part of a customised scrubbing system. Units can be uniquely configured to suit each individual installation case.

Successful installations

NIIK's *Foam Hydrofilter* has been successful tested at the following nitrogen plants:

- EuroChem Azot, Novomoskovsk, Russia
- EuroChem Nevinnomysskiy Azot, Nevinnomyssk, Russia
- Azot, Kemerovo, Russia
- KazAzot, Aktau, Kazakhstan.

NIIK's innovative scrubbing system achieved a very high cleaning efficiency (over 99.9%) during tests on five *Foam Hydrofilters* installed at urea unit 2 at EuroChem's Azot urea plant in Novomoskovsk (Table 1).

PHOTO: YARA

Making fertilizer plants safe

Above: Yara Porsgrunn, Norway. Yara's production units are independently audited for SHE every three years.

We look at safety, health and environmental (SHE) management and hazards at nitrogen fertilizer plants and the importance of the International Fertilizer Association's 'Protect & Sustain' certification scheme.

Catastrophic events in the chemical process industries are categorised as "low-probability, high-consequence occurrences". These naturally receive a huge amount of media attention at the time.

But history teaches us that even these major events fall off the news agenda and are forgotten with the passage of time. That makes effective investigation, reporting and follow-up of catastrophic events critical to achieving a safer operational environment.

Using past mistakes to avoid future errors

Accident investigations provide the opportunity to learn from reported incidents and take corrective action to prevent them from recurring in future. It is essential to translate such learning into design and operational practices[1].

This is certainly the approach taken by leading global urea technology licensor Stamicarbon. All of the international design standards developed by Stamicarbon – which form the basis for its current safe plant design – have been derived largely from experience of past incidents[1].

In Stamicarbon's view, if you can use the mistakes of the past to avoid future errors, you have a good chance of staying in business. When a higher-consequence accident takes place at a process plant, the majority of the plant's personnel are involved, either directly or indirectly. Their involvement can range from being part of the incident investigation team implementing corrective actions or – in the worst case – being directly affected by the accident itself[1].

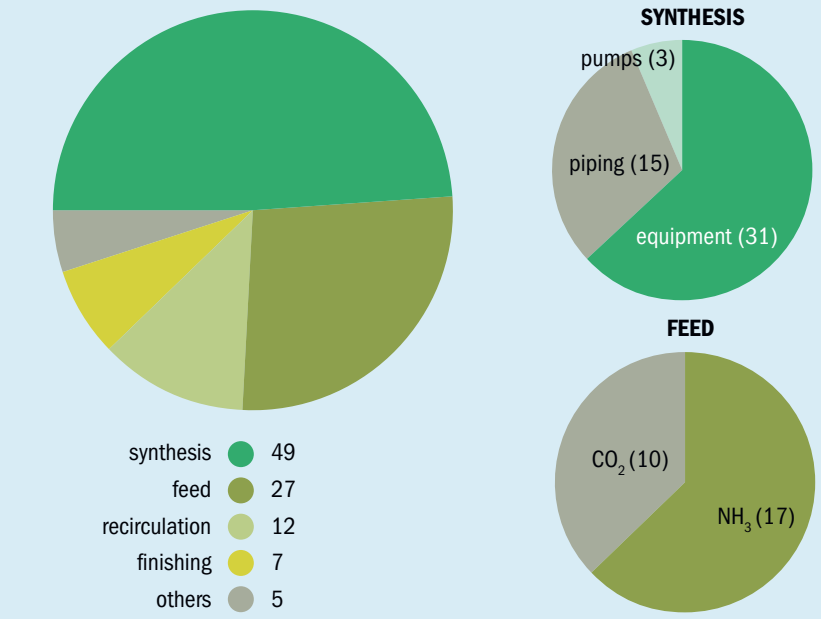
The impact of a catastrophic event on an organisation is profound, especially when co-workers are severely injured or killed. Everybody affected therefore understands the necessity of effective safeguards and operational practices. Indeed, to prevent similar incidents from reoccurring, it is essential, in Stamicarbon's view, to formally embed the lessons from these incidents within design practices and operational regimes[1].

Lessons from urea safety incidents

In 2017, industry websites ammoniaknowhow.com and ureaknowhow.com introduced global open source risk registers for ammonia and urea plants. At the start of 2018, the risk register for urea plants listed 100 safety hazards relating to more than 100 safety incidents, these having led to at least 65 fatalities and 217 injuries[2].

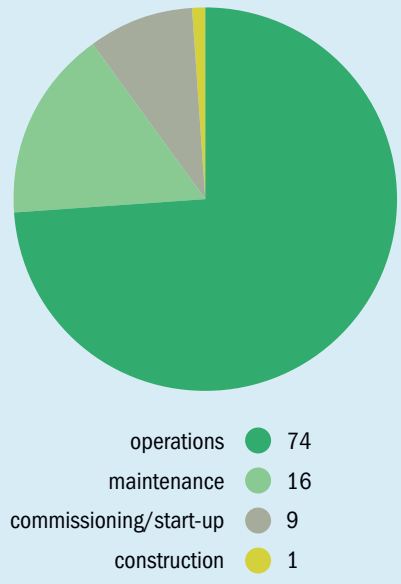
These 100 safety hazards were collated from incident databases, public domain hazard and operability (HAZOP) study results, and incidents reported by of

Fig. 1: **Safety hazards by urea plant section**



Source: UreaKnowHow.com

Fig. 2: **Safety hazards by project phase**



Source: UreaKnowHow.com

ureaknowhow.com members. This register of safety hazards represents a significant proportion of the most critical safety hazards in urea plants. They relate to serious incidents that could potentially lead to fatalities, injuries, loss of containment, compromise the integrity of equipment, or cause serious damage to critical and expensive items[2].

The risk register provides a good overview of urea plant safety hazards. Not only are the hazards identified and listed, each hazard is allocated a risk factor, prevention and mitigation measures are suggested, and reference is made to companies who are able to provide support for implementing these measures. Risk registers are a valuable information source for any HAZOP and safety study of a urea plant.

Where do most safety hazards occur?

A breakdown of the 100 safety hazards by urea plant section (Figure 1) shows these mostly occur in the high pressure synthesis section (49), the feed section (27), the recirculation section (12) and the finishing section (7).

The safety hazards in the high-pressure synthesis section mostly related to high-pressure equipment (63%), high-pressure piping (31%) and high-pressure pumps (6%). Any leak in this section leads to a critical situation due to the release of toxic ammonia, the high pressures and temperature involved, and the presence of corrosive ammonium carbamate. High-pressure equipment is more vulnerable because of the corrosion risk to pressure-bearing carbon steel walls. Ammonium carbamate can corrode carbon steel at a rate of 1,000 millimetres per year.

A significant number of safety hazards occurred in the feed section (27), with 60 percent of these relating to ammonia and 40 percent to the carbon dioxide feed system. A significant part of the feed section is made from carbon steel. Any backflow from high-pressure synthesis will bring this into potential for contact with corrosive carbamate. In HAZOP, it is generally accepted that such a backflow scenario is sufficiently protected against by applying two non-return valves, each of different design. However, analysis of urea plant safety incidents suggests that this assumption/solution now appears to be questionable.

Carbon steel ammonia lines can also suffer from other failure mechanisms – such as vibration, weld failure, process-side corrosion and erosion, atmospheric corrosion and corrosion under insulation.

The carbon dioxide feed system has its own specific and highly critical safety hazard: a small unnoticed carbon dioxide leak can lead to asphyxiation if it occurs in a built-up, unventilated section of plant. Also, in the recirculation section, various important safety hazards exists, such as backflow of carbamate from the high-pressure synthesis to the centrifugal high-pressure carbamate pumps, buffer tank damage and hydrogen explosion risks. In the finishing section, safety hazards include the risk of crystallisation in the urea melt, as well as risks due to cleaning and maintenance in the prill tower, granulator and warehouse.

The top ten equipment items with the most safety hazards are:

1. High-pressure heat exchangers
2. High-pressure vessels
3. High-pressure piping
4. Ammonia piping/valves
5. Ammonia pumps
6. Atmospheric tanks
7. Carbon dioxide piping/valves
8. Carbon dioxide compressor
9. Low-pressure piping (melt, flare headers)
10. High-pressure carbamate pumps.

When do these safety hazards occur?

When the 100 safety hazards are divided according to project phase. (Figure 2), a total of 74 of these are found to occur during the operational phase. However, a relatively large number of safety hazards also take place during the maintenance (16) and commissioning/start-up (9) phases. Relatively large numbers of people are also affected by these hazards due to the volume of contractors on site during these project phases.

Safety hazards during construction, commissioning and start-up

Performing work at elevated heights is a major safety hazard during both construction and maintenance. Although ureaknowhow.com only identified one accident attributable to a construction hazard –

IFA's Protect & Sustain programme

Protect & Sustain is a long-standing safety, health and environmental (SHE) management certification scheme offered to fertilizer companies globally by the International Fertilizer Association (IFA).

It forms one of the three pillars of IFA's global efforts on product stewardship, namely:

- Protect & Sustain certification
- Production benchmarking against four indicators
- The incident reporting portal.

IFA's ethos on product stewardship is industry-wide, encompassing all of the supply chan. It goes beyond the factory gate by putting in place responsible business management practices across the whole of the product lifecycle – in cooperation with the industry's producer, distributor, transport and retail companies.

In general, IFA member companies are expected to adhere to the following 12 SHE principles:

1. Management fully committed to showing SHE **leadership** in fertilizer production, distribution and sales.
2. Strive for **zero harm** when it comes to environmental impact and worker health.
3. Make SHE a **priority** by fully integrating this with corporate policy.
4. Provide the necessary financial and human **resources** to improve SHE performance.
5. **Legal compliance** with all local SHE and safety regulations.
6. Monitor **performance** through annual objectives, targets or key performance indicators.
7. Establish adequate **procedures** to ensure SHE is not jeopardised
8. All staff and contractors are trained and informed to ensure SHE **competence**.
9. **Enhancement** of SHE performance by adhering to hazard and risk assessment principles.
10. Subscribe to SHE and safety management systems and be open to internal and external **auditing**.
11. Voluntarily share **information** on SHE lessons and experiences with IFA member companies externally and with staff and contractors internally.
12. By taking **responsibility** for continual SHE and safety improvements, contribute to the overall social responsibility and accountability of the global fertilizer industry.

IFA has made safety and security a key priority due to their potentially grave reputational risks. This is understandable, given that a global stakeholder reputation survey commissioned by IFA revealed that safety – including security – is the number one driver of the fertilizer industry's reputation.

The prevention measures in IFA's Protect & Sustain programme cover two distinct types of fertilizer incident:

- Operational accidents – product safety
- The misuse of fertilizers as explosives – product security.

Protect & Sustain is now recognised as the *de facto* gold standard for the global fertilizer industry, for both product safety and security. The programme was developed *by* IFA members *for* IFA members – in collaboration with authorised external auditors SGS and DNV GL.

Currently, an impressive 59 fertilizer companies in 57 different countries are Protect & Sustain certified. These include almost all of the leading global fertilizer producing companies. More recently, industry coverage has been expanded by making certification available to the sector's non-producers – including fertilizer distributors, traders, port operators and freight and shipment companies.

While Protect & Sustain is unique – being specifically tailored for fertilizers – it is compatible and overlaps with other widely-recognised international quality management systems. It covers, for example, the quality and SHE aspects of ISO 9001, 14001, 45001 and OHSAS 18001 certification. It also has many points in common with Responsible Care 14001, the management system covering the whole chemical industry. ■

which occurred during the construction of a prill tower – this single incident resulted in at least 12 fatalities. The safety risks from working at an elevated height also exist inside a vertical urea reactor.

The following nine safety hazards were identified during the commissioning and start-up phase:

- Four safety hazards from improperly tightened flange connections on high-pressure equipment and piping. These led to leakages and even two ruptures. One of these four safety hazards, a leaking flange connection of a carbon dioxide pipeline, caused one person to pass out.
- Two safety hazards were attributable to the damage of a sight glass. This led to one fatality and injuries to 18 people. Sight glasses are a major safety risk factor in urea plants.
- One incident of a severe vibration in a high-pressure ammonia pipeline was recorded during start-up flow conditions.
- Another incident was linked to the potential damage to atmospheric storage tanks, and the loose liners of equipment, that can occur when flushed with steam, as this is liable to condense, creating vacuum pressure.
- The remaining safety hazard was attributed to a high-pressure flush pump.

Combined, these incidents led to at least one fatality and injuries to 20 people.

Safety hazards during maintenance

The 16 safety hazards identified during the maintenance phase led to at least 20 fatalities and injuries to a further 19 people. Similar to the construction phase, the relatively high number of deaths and people injured reflects the large numbers of people typically present in the plant during this phase.

Nearly half of the safety hazards during maintenance were connected to a part of the plant that was still in operation or contained process fluid. Such hazards can be mitigated by applying double block and bleed designs. It is also important to be aware of the risks from high-pressure pockets, hydrogen and ammonia explosions during hot work, and the toxicity of ammonia.

Safety hazards can also occur when entering a prill tower or granulator for cleaning activities. Injuries from falling lumps of urea are a risk, for example, and the entrance door to the granulator can close unexpectedly when the fan is put in operation.

Some urea plant maintenance hazards are generic and typical of any chemical pro-

cess plant, such as working at high elevation, asphyxiation in confined areas and accidents with cranes.

Safety hazards during operation

Some 74 safety hazards were associated with fully operative plants. These led to at least 28 fatalities and injuries to an additional 173 people injured. Many of these safety hazards were linked to process fluid leaks.

In a urea plant, leaks can be caused by corrosive ammonium carbamate finding its way into stainless steel crevices. Such crevices can occur due to improper alignment/tightening of flanges, or result from improper design of valves or accessories.

The ongoing corrosion of stainless and carbon steel parts and piping by highly corrosive ammonium carbamate leaking must be avoided. This makes the proper design, operation and maintenance of leak detection systems critical for high-pressure equipment, flanges, and valves.

High pressure leakage of ammonium carbamate results in the formation of very hard crystals which erode the sealing areas. Once a leaks occur, it is nearly impossible to stop these by tightening bolts. Adequate tightening of flanges and other connections can be challenging in a urea plant because of the limited choice of suitable construction materials. Employing experienced fitters is important. Attempting to stop leaks during operation – by hot bolting/torqueing and installing clamps – has led to five fatalities and four people being injured and should therefore be avoided at any time.

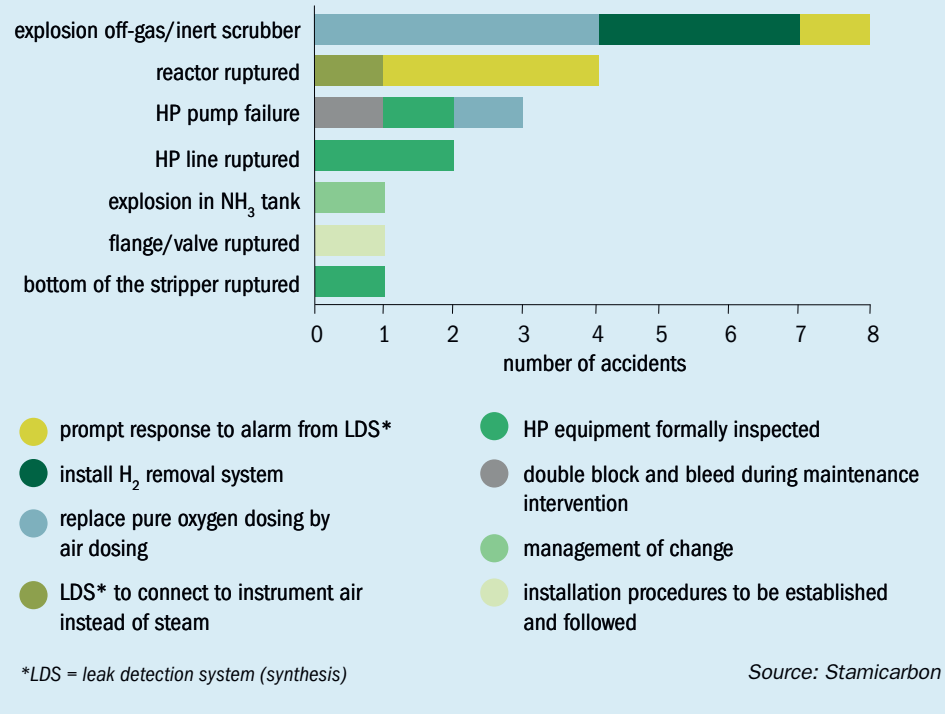
Other safety hazards that also require full and proper attention include backflow, contamination, vibration, atmospheric corrosion, or corrosion beneath insulation.

Seven safety hazards were linked to the presence of hydrogen in the feed streams to the urea plant. Dissolved hydrogen in liquid streams can lead to its presence in unexpected sections of the urea plant. Hydrogen can also enter the urea plant, via process water and/or drain systems, during integration with an ammonia plant.

Analysis of catastrophic incidents

Individual nitrogen sector companies are also collating and analysing safety incident data to help prevent accidents in future – and check that suitable safeguards are in place. Fatima Fertilizer, for example, Pakistan's largest fertilizer producer, has collected data for major urea plant accidents worldwide stretching back 50 years[3].

Fig. 3: **Urea accident vs learning effect**



*LDS = leak detection system (synthesis)

Source: Stamicarbon

The company has identified the root cause of each accident. Of the major accidents, there were:

- Eight incidents of explosions in the scrubber vapour line
- Four incidents of reactor ruptures
- Three incidents of high-pressure pump failures
- Two incidents of high-pressure piping failure
- Two incidents of stripper bottoms rupturing
- One incident of an explosion in an ammonia water tank.

Learning from incidents

In 2017, Stamicarbon invited urea manufacturers to help build a urea incident database. The idea was to create an open, shared SHE (safety, health and environmental) portal that the whole industry can access and benefit from. Stamicarbon hopes that by launching the portal, and enabling the sharing of experiences, the industry can collectively learn from past incidents and near misses – and thereby improve urea plant safety by gaining a better understanding of operational risks[1].

Stamicarbon first recognised nearly 50 years ago that recording major urea plant safety accidents would enable the company to subsequently improve its process design. As well as simply capturing data, Stamicarbon has also conducted its own root cause analysis of the majority of these events (Figure 3).

The company's original database covered 20 accidents over the period 1967 to 1981. Eight of these were linked to hydrogen explosions. The takeaway lesson from this was to provide the CO_2 supply with a hydrogen removal unit and replace pure oxygen dosing with air dosing instead. No hydrogen explosions have ever occurred in plants where both of these control measures have been implemented. This, says Stamicarbon, clearly shows that earning from past incidents clearly does pay off![1]

Because its database originally contained only details for 20 major accidents, the question for Stamicarbon was whether these inputs were sufficient to fulfil company objectives set out in its mission statement, i.e. Can the company identify common causes, and failures of preventative measures, and correct these before a high-consequence incident actually takes place? This provided the main impetus behind the 2017 launch of the company's open-access SHE portal – and the invitation for other companies to share their data on urea safety incidents for the common good[1]. ■

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2. Baboo, P., et al., 2018. Lessons learned from urea incidents. *Nitrogen+Syngas* 356, p51.
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The International Fertilizer Association (IFA) is helping to fully develop the career potential of younger employees through its Young Professionals initiative. This is providing a new generation of industry professionals with access to mentoring and career development advice. It also gives individuals a chance to network with their peers, as well as subsidising attendance and participation at international conferences.

To support IFA's new initiative, *Fertilizer International* magazine is running a series of profiles featuring industry young professionals. These highlight the wide range of attractive and rewarding career options available to young people in the fertilizer sector. In this issue, Pranjali Yadav of IFFCO talks to us about her career.

PHOTO: IFA

Young professionals

Pranjali Yadav, 26, senior engineer

How did your career in the industry start?

I graduated with a degree in chemical engineering from India's Banasthali University back in 2015. IFFCO was hiring a number of fresh graduates as apprentices that year, including chemical engineers. So I applied for the post and luckily got through successfully. The job then became permanent after I'd completed my one-year apprenticeship and a follow-up year of training. Currently, I am a senior process engineer in the technical department of IFFCO's Phulpur production unit.

What achievement are you most proud of?

Practical learning is what every process engineer needs at the start of their career. I was involved with the commissioning of a gas turbine and a CO_2 removal project during my apprenticeship. Those experiences gave me a huge opportunity to both learn and be involved – from making the punch lists, to witnessing the priming of a pump, the steam blowing of lines or hydtrotests.

Being part of the task force for an ammonia-urea audit was also full of insights. It also gave me the opportunity to deliver presentations in front of top officials at meetings.

What do you find most rewarding about your job?

Honest feedback from my seniors, good or bad, helps me to improve and deliver more. I always value praise for a job well done. Just one kind word of appreciation – a simple "good!" – boosts my dedication to work. But a deeper sense of satisfaction also comes from knowing that my contribution towards IFFCO's performance ultimately benefits those who buy our products – the Indian farmer.

What hurdles have you had to overcome?

When I joined IFFCO, I was a raw and inexperienced graduate. So learning how to apply theoretical concepts practically was a real challenge. I've definitely been on a learning curve. One time, for example, I took a very long time completing a calculation given to me by a senior colleague. But he did say something very valuable to me, "Time is a key in any organisation. Don't wait to make things perfect, make them optimum."

How do you get the best from yourself and your colleagues?

Being positive, acknowledging the contribution of others in the work place, and showing a little humility and gratitude can reap the best results. When working as a team, you also need to take full advantage of one another's strengths. What helps keeps me motivated is learning about plant and the production process and accepting every opportunity that comes my way.

Has mentoring been important to you?

Yes, definitely! Raw clay needs to be moulded to achieve the desired shape. Likewise, for a person to reach their full potential, some guidance is needed to bring out their best and channel their skills and energy in the right direction. Fortunately, I have benefitted from great mentors and senior colleagues in the workplace. I have always been able to develop the right skills for the job thanks to their help and guidance.

How will your job and the industry change in future?

Automation and digitisation are big trends on the production side of the business. The move to distributed control systems is providing us with better process monitoring, for example. Cloud computing also helps us to store our standard operating procedures in one single secure place. I also think the market will demand a pragmatic shift towards organic and innovative fertilizers in future. IFFCO is already venturing into organic farming in India through a collaboration with the Sikkim state government. As a company, we've also introduced a range of fertilizers that incorporate nanotechnology. That's a particularly exciting development to watch out for!

What advice would you give to anyone about to embark on a career in the sector?

Always try to be inquisitive and never stop learning. My attitude is that every task is actually an opportunity in disguise. ■

March-April 2020

phosphates & potash INSIGHT

■ Contents

Operational Barracuda bucket wheel excavator

PHOTO: TKIS

Phosphate and potash mining update

We look at state-of-the-art technology used in phosphate and potash mining, including equipment and systems for excavation, tailings thickening, transport, tunnelling and processing.

The *Barracuda* excavator: hard mining made easy

Germany's **thyssenkrupp Industrial Solutions (tkIS)** introduced its new *Barracuda* range of bucket wheel excavators in 2016. These compact mining machines use a larger number of teeth per bucket to cut materials with a uniaxial compressive strength of up to 50 MPa. The *Barracuda*'s innovative design allows harder material to be excavated, including phosphate rock, potash and limestone, without the need for drilling or blasting operations.

By combining ore excavation, loading and the transport within a single machine, the *Barracuda* can seamlessly replace a complex system of multiple machines with a single mining unit.

thyssenkrupp offers four versions of the *Barracuda,* each with different ore transport configurations. They range from a compact machine and conveyor – for a basic extraction process – to the advanced *Barracuda* C machine. This combines a compact bucket wheel excavator with a discharge boom operating in tandem with a conveyor system[1].

The *Barracuda* has three particular features that make it an attractive excavation option for mine operators, according to tkIS:

- Streamlines ore transportation
- Offers predictable operational costs
- Able to eliminate pre-blasting.

In ore transport, the possibilities for integrating the *Barracuda* with continuous mining/conveyor systems – combined with its ability to excavate hard materials – widens the range of potential mine applications. It can also deliver major cost reductions in comparison to conventional truck transportation. The machine's electrical drive can also reduce the carbon footprint of mining operations.

"We already identified some cases where one *Barracuda* shows potential to replace a combination of more than 10 single units of other mining equipment, providing an optimisation of the operation and maintenance efforts required in the mine," says Paulo Costa, global head of mining systems at tkIS[1].

thyssenkrupp offers a flexible contract for the *Barracuda* that covers the wear of selected machine parts and guarantees their replacement. This uses a 'value-based model' to accurately predict costs for component wear over the machine's lifetime – one of the main sources of operational expenditures for bucket wheel excavators.

"The offering is part of the company's digitalisation initiative," said Stefan Ebert, global product lifecycle manager for tkIS mining systems[1]. "It is a great experience to challenge ourselves [about] the individual needs and risk profiles of our customers and flexibly adjust our offering accordingly."

But is the elimination of pre-blasting that is the main factor which overall makes the *Barracuda* a leaner, more cost effective and safer mining process option.

Conventional bucket wheel excavators, are unable to cope with harder ore materials and – unlike the *Barracuda* – still require blasting to fracture *in-situ* rock prior to extraction. The need for pre-blasting can add more than $0.2 per tonne to extraction costs – a major cumulative cost for multi-million tonne mining operations. The *Barracuda*, by removing the need for drilling and blasting, can therefore offer significant cost reductions, especially for mine expansions or new mine projects which require investment in new equipment anyway. The use of *Barracuda* mining machines also offer a more sustainable alternative to blasting, which is subject to increasingly stringent environmental regulations for noise, fumes, dust and vibrations[1].

Mining companies have been quick to buy the *Barracuda*. Italian-Thai Development Plc has placed an order for two, as has China's Huaneng Group. Commissioning of these machines is advanced with both companies expecting to begin operations in the coming months[1].

The ideal method to dewater tailings?

The mining industry is urgently looking for alternative methods of storing tailings. The disastrous tailings dam collapse at the Brumadinho iron ore mine in Brazil in January highlighted the ongoing risks associated with dam failure – particularly the loss of life and environmental damage that can result.

One of the safest ways of reducing or eliminating such risks is to reduce the water content in tailing storage facilities (TSFs). This has the added advantage of increasing water recovery – a major environmental and financial concern when mining in dry climates – and reducing the installation's overall geographical footprint.

The options for reducing stored water content – so-called dry tailings solutions – still face key challenges, however. These include increased operating and equipment costs, and how to handle the dry waste solids that are generated. The technical challenge of dewatering tailings is also exacerbated by particle-size reduction, an industry-wide trend that increases plant yields, improves water efficiency and reduce manpower and electricity costs.

Nevertheless, dry tailings solutions do offer substantial cost reductions over the total lifecycle of the mine. This overall savings is revealed when the costs of closure, land, water balance and carbon footprint are all taken into account, in addition to the upfront capex and opex of the project.

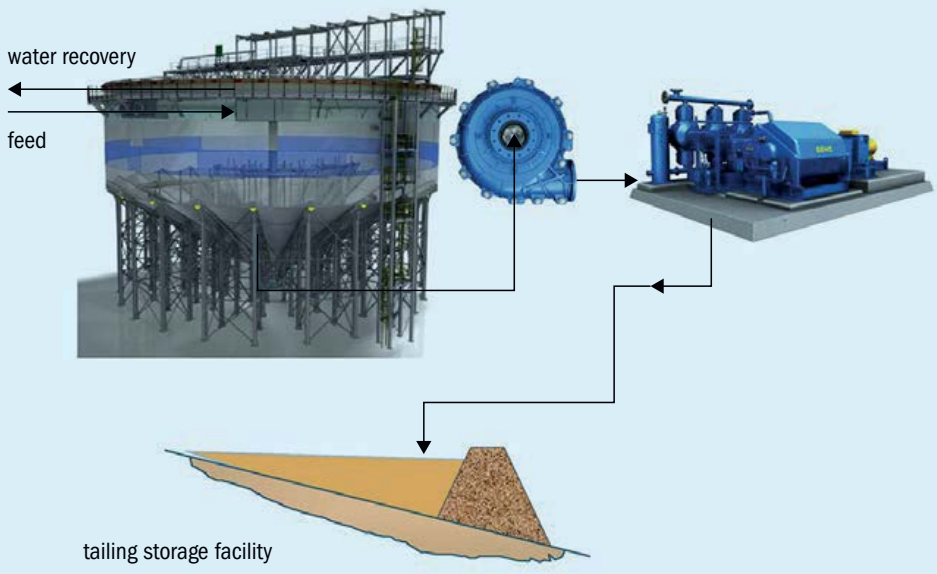
Because every mining application and every ore is different, no single approach provides the best universal method for dewatering tailings. Below, **Weir Minerals** highlight the main advantages and disadvantages of three promising technologies able to deliver dry tailings, as well as their associated cost factors[2]:

- Paste thickener with *GEHO*® pump
- Continuous separation with centrifuge
- High pressure filtration with filter press.

Isodry™ paste thickener with *GEHO*® pump

In this flowsheet, a paste thickener is used to produce an underflow paste (65% w/w) without any free water (Figure 1). This method combines a Weir Minerals *Isodry*™ paste thickener system with a *Warman*® centrifugal pump feeding positive displacement pump, such as a *GEHO*® piston diaphragm. The resulting high solids content slurry is transported by pipeline to the TSF.

Fig. 1: **Dry tailings solution that combines and *Isodry*™ paste thickener system with a *GEHO*® pump**



Source: Weir Minerals

Combining a paste thickener and a positive displacement pump provides the easiest disposal method for slurries without free water. The automation of these operations would require advanced process controls and pump management.

Weir carried out a study to mitigate the risks and design the best system for this disposal method. A pilot pipe loop test was used to find the optimum balance between solids content and pressure drop in pipe line.

The study considered three paste thickeners with a 60-degree cone angle and a high wall height. Advanced process control is necessary to make sure the paste thickener will produce the desired solids content in the underflow – and to control the pumping system and its standby/duty mode. The desired underflow solid content was 65 weight percent with 1,000 m^3/h flow rate at over 200 bars, although Weir Minerals has previously delivered a pumping project for phosphate tailing with 70 percent solids.

Continuous separation with centrifuge

To achieve a higher solids content than is possible by paste thickening, tailings needs to be dewatered using a mechanical separation process.

The continuous separation equipment options are limited to decanter centrifuges, vacuum disk filters and screw presses. The solids contents obtained using centrifuges and vacuum disk filters are both similar, based on Weir Minerals' experience, with a similar opex/capex too.

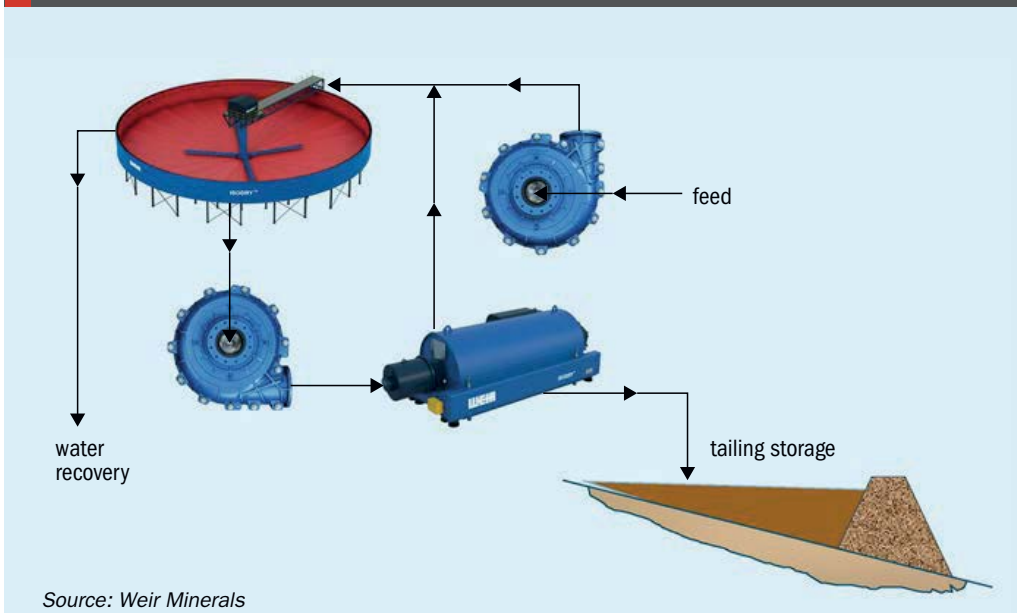
Continuous separation is capable of achieving water contents above what is possible with a paste thickener. While dryness levels are still below those delivered by a filter press – which are the highest achievable – this method has the advantage of being continuous not a batch process.

Although disk filters are commercially available in higher capacities, decanter centrifuges will provide a better separation if high percentages of ultrafine particles (<20µm) are present. Therefore, for each project, performing a separate feasibility test for a centrifuge vs a vacuum disk filter can be a valuable exercise.

The Weir Minerals study focussed on a decanter centrifuge producing a solids content of 75 percent. A thickener is also incorporated into the flowsheet to increase and maintain a constant solids content to the separation machine (Figure 2). The use of a single thickener should have a positive effect on capex and opex by reducing the number of centrifuges required

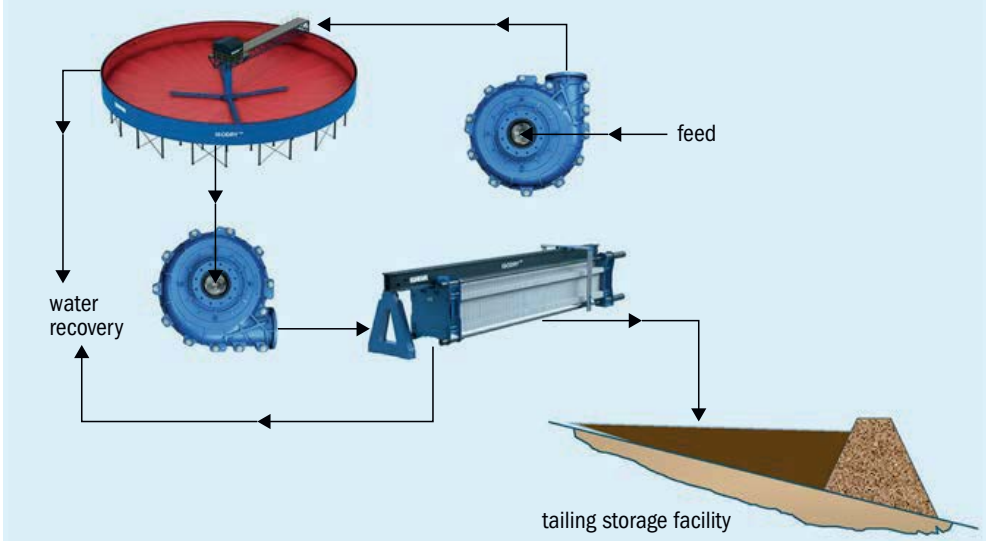
Flocculant will need to be added to the decanter centrifuge feed if clear water is required, although this can double opex. However, in the proposed flowsheet, flocculant is only added to the thickener. The decanter centrifuge actually produces the highest solids content without the addition of flocculant in the centrifuge feed. Concen-

Fig. 2: **Tailings dewatering by continuous separation with a centrifuge**



Source: Weir Minerals

Fig. 3: **High pressure filtration by filter press**



Source: Weir Minerals

trate from the centrifuge is fed back into the thickener and the thickener overflow is the only source of water recovery.

A belt conveyor could be used for conveying separated solids from the centrifuge. The other transport option – after pilot test pumping – would be a positive displacement pumps such as a *GEHO®* hydraulic driven piston pump.

As a dry tailings solutions, the decanter centrifuge should have the following features:

- High solid capacity
- High torque gearbox
- High speed to separate small particle size
- Low energy consumption – because the main operating cost of this machine is the electrical power (along with flocculant, if needed).

The Weir study considered a system with: one thickener, 18 decanter centrifuges, feed pumps, and one high solid content positive displacement pumping system – with automation to control the feed, machine parameters and washing of the machine when needed.

High pressure filtration by filter press

Filter presses are the best available machines for achieving the highest dryness levels that are often requested for dry stacking projects. The filter press is a batch machine, sized according to its operating volume and cycle time. It can produce a wide variety of tailings products by adjusting the timing of the cycle.

Filters do not require any flocculant. This is because the filtrate is only 'dirty' momentarily, in the initial seconds of the filtration process, becoming crystal clear as soon as the cake is formed.

Modern high capacity filter presses for tailings now have a much shorter cycle time and larger production capacity, thanks to the increase in their plate size.

Modern filters typically have between 100-200 large plates and a cycle (mechanical operation) time of 2-5 minutes. Tests are required to optimise the cycle time and the different steps between feeding, squeezing, cake blow etc. The product with the highest dryness is achieved through high-pressure squeezing. A pressure of up to 15 bars is usually sufficient, although in some projects we observed an operational difference at over 20 bars. The cake blow stage, for a large surface filter press, needs large motor compressors (over 500kW) and receivers. These auxiliary compressors can be opex intensive, if not properly designed and for projects where no compromise on dryness is permitted.

The filter cloth is also an important parameter to consider, as the quality of the cloth can influence filtration properties. The cloth itself is also a wear part and generally needs to be changed every few thousand cycles. In high capacity filter presses with a short cycle time, however, filter cloths only need to be changed between four and twelve times every year. Large plates are perfect for high capacity operation, but removing and installing new cloths can be labour intensive, as people are needed to supervise operations and physically change the cloths.

In our study, we considered one thickener, nine filter presses plus all their auxiliaries (feed pumps, valves, squeezing system, compressors, conveyors etc.) and a dry stacking system (Figure 3). Producing a cake with the desired solids content (85% w/w) achieved a water recovery of 95 percent. The gains from this method, in terms of the reduction of TSF volume at an eight degree angle of repose, come at a considerable cost – requiring 10 times more opex, 20 times more capex, together with a team in a dewatering plant to operate the filter press plant.

The ideal dewatering solution?

All flowsheets have their advantage and disadvantages. There is no single ideal method or flowsheet for dewatering tail-

Water, mining and the phosphate industry

PHOTOS: FLSMIDTH

Above left: Colossal filter demo plant. Above right: Stable GeoWaste generated by the EcoTails process.

The phosphate industry consumes vast amounts of water and generates large volumes of tailings. Recovering water from these tailings economically, and disposing of the solids, is an increasing challenge for the industry's miners and producers, as FLSmidth's **Lucy England** explains[3].

Shift to dry stack tailings?

The use of pressure filters to recover water has been commonplace in the mining industry for many years. Yet the majority of these are small, low-throughput installations – as the cost of large-scale tailings filtration generally becomes too prohibitive at higher tonnages. Tailings are therefore typically dewatered using small pressure filters, with subsequent air drying of the filter cake to an optimum moisture content. Using trucks for tailings transport and placement also adds an additional cost of over $4 per tonne.

To mitigate the risks associated with wet tailings disposal, many mining companies are looking for a step change in filtration and waste disposal technology. This will be necessary if dry stack tailings are to be developed – as a viable replacement for tailings dams – with low enough capital and operating costs to make high-tonnage, low-grade operations viable.

The *Colossal* filter from FLSmidth

FLSmidth is one of the world's leading suppliers of solid-liquid separation equipment. The company has been at the forefront of many product developments in thickening and filtration throughout its existence, stretching back more than a 135 years.

There is currently a pressing need to treat, reuse and recycle wastewater, according to FLSmidth. In its view, the mining industry needs to stop thinking of wastewater as waste and start thinking of it as a new industrial water source instead.

As part of this shift in thinking, FLSmidth believes it is vital to recycle as much water from tailings as possible – especially given that the scale of mine production is increasing as water is becoming scarcer. Consequently, there is a particular need for technologies able to dewater large tonnages of tailings, with minimal power consumption, and utilises larger equipment to benefit from economies of scale.

FLSmidth is currently working on solutions that minimise the use of wet tailings, as well as developing methods that make tailing more stable by recycling as much water as possible. To meet industry's requirement for a large-scale filter press, FLSmidth has developed the *Colossal* filter. This offers the following benefits:

- Reclaim up to 95% of water for re-use, cutting your costs
- Environmental impact is reduced
- Dry cake material eliminates risk of failures
- Dry cakes can be safely conveyed and even compacted
- Dry material can be restored and re-vegetated.

FLSmidth has also designed a larger *Colossal* filter for a co-mingling process called *EcoTails*™ developed in collaboration with Newmont (formerly Goldcorp). This is a fully-integrated waste solution that combines waste rock with dry tailings to create a material called *GeoWaste*. The tailings fill the void space between rock particles, so reducing oxygen flow and acid rock drainage. The presence of coarse waste rock particles also provides *GeoWaste* with good shear strength and physical stability. The *EcoTails*™ process also recycles 90 percent of process water.

The mining industry has traditionally been comparatively slow at adopting new technology and methods, with the capital and operational costs of new equipment being typical barriers to adoption.

"The big question is usually who will be the first to adopt a new approach as new solutions have to be proven before commercial use and there is perceived higher risk in being the first adopter," says Lucy England of FLSmidth's wet processing mining division. "Sometimes, the risk is higher when you don't do anything. Eventually, we hope to see the industry change fully to dry stack tailings, eliminating the risk of wet tailing dam failure."

England adds: "We strongly believe that water management will be a limiting factor for many mines in the near future, if not already. The time has come to recycle, treat and reuse as much water as we can." ■

1 47 2 48 3 49 4 50 5 51 6 52 7 53 8 54 9 55 10 56 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46

ings which performs best in every key criteria described above. The 'perfect' solution is instead site- and project-specific, being influenced by the desired characteristics of the tailings to be produced, the location of the TSF and how the customer wishes to manage their tailings.

A pilot test is therefore a necessary prerequisite to properly choose between the different dewatering methods. Allocating time and money on this preliminary step is well spent, as it will result in an optimised project and mitigate the risks that can be associated with tailing projects. Close collaboration between various experts in separation, slurry transport and geotechnics is also required to discover the optimum solution for successful tailings management.

Slavkaliy potash project order

FLSmidth secured a DKK 360 million ($53 million) order from CITIC Construction in February to supply liquid-solid separation equipment to the under-construction Slavkaliy project in Belarus. CTIC is the construction contractor for the greenfield mining project.

Slavkaliy is currently developing a potash mine and production complex to exploit the Starobinskoye potash deposits in the Nezhinsky area of Belarus. The order placed with FLSmidth includes a large number of thickeners, clarifiers, pan-filters and horizontal belt filters.

The items will be supplied as a number of fully-automated 'equipment islands'. These will be integrated within the plant's overall automation system, designed previously by FLSmidth.

Equipment deliveries will start by the end of this year and continue into 2021. FLSmidth engineers will then supervise the assembly and commissioning of equipment to ensure the timely completion of the project. The new complex is expected to be completed before the end of 2023. It will have the capacity to produce between 1.1-2.0 million tonnes of potassium chloride annually.

Manfred Schaffer, FLSmidth's mining president, said: "After the plant engineering order booked in the third-quarter of 2019, we are especially pleased to have now secured this equipment order from CITIC Construction, the contractor for Slavkaliy.

"We are confident this will be a leading, cutting-edge operation with a strong focus on productivity, efficiency and sustainability. The significant level of automation and digitalization, in combination with our equipment, will also mean the lowest possible on-site energy consumption."

EuroChem's Usolskiy and VolgaKaliy projects

EuroChem Group's $2.1 billion Usolskiy project in Russia's Perm region is now fully operational, while engineering work continues at its sister project, the $2.9 billion VolgaKaliy mine in the Volgograd region, to enable it to begin production in late 2020.

The same potash mining equipment is being installed at both mines. *Ural-20R* mining machines, transfer hoppers and shuttle cars will be used to transfer ore to each mine's main line conveyor systems:

- ***Ural-20R* mining machines:** these cut an arched roof 3.1 metres high and 5.1 metres wide. Each machine is approximately 12 metres long and weighs 100 tonnes. They are crawler-mounted and electrically-powered each with an average annual capacity of around 600,000 tonnes.
- **Transfer hoppers:** these operate immediately behind the *Ural-20*. Being electrically-powered, and approximately 8.4 metres long and 2.3 metres wide with a capacity of 16 tonnes, they are equipped with a conveyor system to transfer ore to waiting shuttle cars.
- **Shuttle cars:** these bring ore to the conveyor system, which in turn transports the ore to the shaft where it is lifted to the surface. The cars operates using a trailing cable on a reel, allowing them to travel a distance of up to 400 metres. Each shuttle car is approximately 9.0 metres long and 2.6 metres wide, weighs 19 tonnes, and has a 17 tonne payload capacity.

The *Ural-20R* continuous mining machines are manufactured by **Kopeysk Machine-Building** in Russia's Chelyabinsk region. Each of these machines is capable of mining an impressive 600,000 tonnes of ore annually. Usolskiy was operating 20 Ural units last year and will add more over time to keep up with the mine's ramp-up schedule.

Veolia to supply VolgaKaliy expansion

EuroChem Group has selected **Veolia** as a technology provider for the expansion phase of its VolgaKaliy potash project in Russia's Volgograd region.

The mine, which began production in 2018, will incorporate Veolia's crystallisation technology as part of an expansion scheduled to begin in 2021.

Veolia's *HPD PIC™ Crystallizer System* will be used to manufacture two million t/a of high-purity potassium chloride fertilizer from brines extracted from conventionally-mined potash ore. Veolia Water Technologies will provide the major process equipment required, including multiple *HPD PIC™ Crystallizers*, recirculation and transfer pumps, vapour condensers and centrifuges.

"With their proven experience and talented team, EuroChem is pleased to be working with such a strong partner as Veolia," said Clark Bailey, EuroChem's head of mining "The expansion phase of our VolgaKaliy project will increase the plant's capacity to 4.3 million tonnes per year of potash, in grades suitable for both agricultural and industrial applications."

Klaus Andersen, CEO of Veolia Water Technologies, added: "We are proud to partner with EuroChem on this prestigious project. With the experience from more than 50 references in the fertilizer market, we were able to offer a custom-built system that offers the flexibility to meet a wide range of production requirements."

State-of-the-art rail wagons

EuroChem ordered 700 bespoke rail wagons for Usolskiy from **United Wagon** in 2018. Each wagon has a volume of more than 100 cubic metres and is fitted with heavy-duty 25-tonne-axleload bogies, enabling it to carry approximately 77 tonnes. The larger volume of the wagons also lowers their centre of gravity, making them more stable and difficult to overturn.

Wagon hatches are stamp-welded, improving durability and rigidity, and fitted with wear-resistant moulded rubber strip seals. The inside of each wagon is also protected from corrosion using a two-component polymer coating. The new wagons can be used for up to eight years, or one million kilometres [620,000 miles] between overhauls, says United Wagon. That compares with just two years or 110,000 kilometres (68,000 miles) for conventional wagons.

Similarly, **K+S Potash Canada** (KSPC) ordered 531 custom-built rail cars for its Bethune potash mine site in Saskatchewan. The rails cars, divided between three trains, are used to transport potash from

the Bethune mine to KSPC's Port Moody potash facility in British Columbia. The rail cars begin their journey along a 30 kilometre spur constructed by Canadian Pacific (CP). This connects the 14 kilometres of rail track owned and operated by KSPC at Bethune to CP's mainline rail track at Belle Plaine.

The rail cars, designed by **National Steel Car**, can be loaded while in motion and are built to an innovative design. They have the capacity to hold the same volume as a regular rail car while being slightly shorter in length. This optimises rail transport and the timely and efficient delivery of products.

"When trains arrive at our facility in Port Moody, they are unloaded by automatic conveyor to our warehouse or directly onto a ship at one of the world's most modern potash handling facilities," said Steffen Brill, K+S Group's senior director for logistics procurement and execution.

The 531 rail cars met KSPC's initial requirements for weekly ore transport to Port Moody. The procurement of more cars was planned for when production at Bethune reached full capacity, according to Brill, to transport additional product to the US market.

The Woodsmith mine project

Sirius Minerals is developing the Woodsmith Mine project in the UK. This under-construction polyhalite mine is located six kilometres south of Whitby on England's North Sea coast. Project construction, which began in May 2017, is scheduled to be completed in 2023.

Sirius expects the polyhalite project to ramp-up to its full capacity of 10 million t/a by the end of 2024.

The project has been in six-month review since September 2019, following a decision by Sirius to withdraw its second-stage financing plan. Mining giant **Anglo American** subsequently stepped in, making a firm £405 million cash offer for the Woodsmith Mine project at the end of January. The takeover was due to be completed on the 17th of March.

The Woodsmith Mine will access an underground polyhalite seam (up to 70 metres thick) at a depth of around 1,500 metres via two deep shafts – one shaft dedicated to production with the other retained as a service shaft. Shaft sinking contractor **DMC Mining Services** will use the Herrenknecht shaft boring roadheader (SBR) to construct both shafts. The SBR successfully completed the excavation of two deep shafts for BHP's massive Jansen potash in Saskatchewan, Canada, recently.

PHOTO: SIRIUS MINERALS/HERRENKNECHT

Sirius Minerals Herrenknecht shaft boring roadheader.

The SBR is suspended from cables connected to winches on the surface. As the SBR descends, a permanent lining is inserted in sections from an upper working deck.

The SBR is designed for much higher sinking rates, while also providing maximum safety for working personnel, compared to conventional shaft sinking methods. The SBR is equipped with a roadheader boom and a rotating cutting drum. This enables the shaft diameter being cut to be varied between eight and twelve metres. The telescopic SBR boom allows the entire shaft cross-section to be excavated to a depth of one metre in a single cycle.

Primary mine development within the polyhalite seam – and most mine production – will be by conventional 'room and pillar' mining using continuous miners (CMs). Polyhalite will be also extracted by drill and blast (D&B) production, easing a combination of large drill rigs and battery-powered load haul dump (LHD) loaders.

During the first 25 years of the Woodsmith Mine's life, approximately 35 percent of the total mined tonnages will come from the D&B production areas, with 65 percent coming from the CM production. Flexible conveyor trains (FCTs) will be used behind the CMs to transport ore. Sirius made the decision to adopt shuttle cars and large battery LHDs to provide more flexibility in the onward movement of ore from the CM and D&B production units. ■

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Innovations in froth flotation

Newly-developed froth flotation schemes, equipment and reagents are improving selectivity and the grade and recovering of phosphate concentrates

JESA TECHNOLOGIES

Two-stage flotation optimises performance

Reverse double flotation

Most sedimentary and igneous phosphate ores contain unwanted impurities that need to be removed prior to chemical processing. Froth flotation is currently the most economical beneficiation technique for separation and removal of impurities from phosphates around the world.

Many phosphate reserves beneficiated today are associated with carbonates and silica. Upgrading this type of phosphate ore can be costly and requires many beneficiation processing steps – such as crushing, scrubbing, classification, milling, de-sliming, attrition, direct or reverse flotation, etc. – to produce a phosphate rock concentrate suitable for the production of phosphoric acid.

The separation of carbonate from phosphate has long been recognised as one of the most challenging tasks in phosphate ore beneficiation. This is due to similarities in the physical and chemical properties of phosphate and carbonate minerals. Processing a phosphate ore that contains finely disseminated carbonate, as well as silica impurities, therefore requires a carefully designed flotation scheme. The selection of the correct reagents is also extremely important – to maximize phosphate recovery and ensure reagent consumption is optimised.

Single-stage vs two-stage reverse flotation

Single-stage reverse flotation is used to upgrade ore in many current phosphate beneficiation plants. This simultaneously floats carbonate and silica as tailings, leaving the phosphate sink as the final concentrate. Although this type of flowsheet benefits from simplicity, in practice, it can limit phosphate recovery for those ores that contains significant fine material. For these ore types, double reverse flotation is often preferable and recommended because it can improve P_2O_5 recovery, reduce foaming, and lower reagent consumption and cost. In this two-stage process, carbonate is floated first, to remove all fines and slime carbonates from phosphate, followed by a second flotation stage to remove silica and clays.

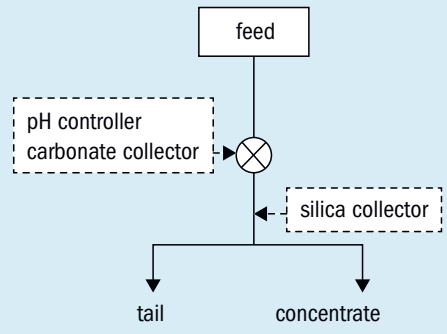
Pilot plant tests

Flotation tests were conducted on a North African phosphate ore at JESA's pilot plant, in Lakeland, Florida. The main purpose of the test work was to evaluate flotation performance using two flotation schemes. The first scheme used a single reverse flotation stage to float carbonates and silica together in one step. Whereas, in the second scheme, carbonate and silica were floated separately in two stages.

For both schemes, the ore was firstly scrubbed and classified at 160 microns to generate oversize and undersize products. The +160-micron product was then milled in closed circuit. The -160-micron material obtained from milling was then combined with the sample's original -160-micron undersize. This combined product was then attrition scrubbed and deslimed at 40 microns to generate flotation feed for testing. The resulting -160 + 40 micron feed contained approximately:

- 27 percent P_2O_5
- 7 percent insoluble material
- 1.3 percent MgO.

Fig. 1: **Single stage reverse flotation**



Source: JESA Technologies

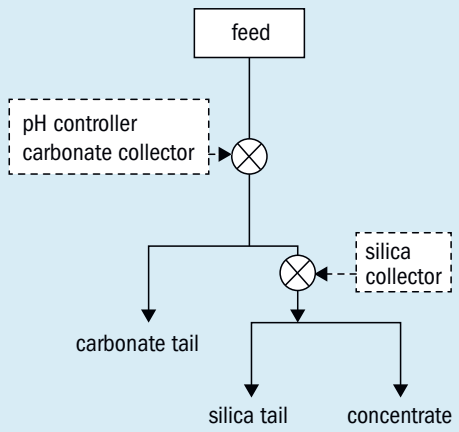
Calcite and dolomite were the main gangue minerals present. Both of these carbonate minerals together with silica needed to be removed from the feed to achieve a target grade of more than 30 percent P_2O_5 in the phosphate concentrate.

Flotation tests were conducted using a Denver D12 laboratory flotation machine. The solids were pulped with Lakeland city tap water at ambient temperature. The feed was conditioned at a slightly acidic pH (less than 5.3) with phosphoric acid.

For single-stage flotation, the carbonate and silica were floated in one step as a tailing product, leaving the phosphate sink as a final concentrate (Figure 1). The slightly acidic feed was conditioned with a carbonate collector (phosphate ester) for two minutes, and a silica collector (amine) for 30 seconds, prior to flotation.

For two-stage flotation, carbonate and silica were floated separately. A fatty acid type carbonate collector was added in the first stage and an amine collector for silica in the second stage (Figure 2). The sink material from the carbonate flotation stage was de-slimed at 40 microns prior to silica flotation.

Fig. 2: **Two-stage reverse flotation**



Source: JESA Technologies

Pilot plant results

The flotation results for single- and two-stage reverse flotation are shown in Tables 1 and 2, respectively. These demonstrated that double reverse flotation in two stages separated carbonate and silica from phosphate very effectively. Carbonate flotation is more selective when performed separately from silica flotation – with about 58 percent of the MgO being removed in the carbonate tail compared to 45 percent using one flotation stage. The two-stage flotation scheme also achieved a higher concentrate grade (31.0% P_2O_5) and phosphate recovery (91.5%) compared to the one-stage scheme (29.8% and 87%, respectively).

Table 1: **Test results for single-stage reverse flotation**

Product	Wt. %	Assay, %			Recovery, %		
		P_2O_5	Insol.	MgO	P_2O_5	Insol.	MgO
Tail	19.5	18.8	14.9	2.9	13	44	45
Concentrate	80.5	29.8	4.7	0.9	87	56	55
Feed	100	27.6	6.7	1.3	100	100	100

Source: JESA Technologies

Table 2: **Test results for two-stage reverse flotation**

Product	Wt. %	Assay, %			Recovery, %		
		P_2O_5	Insol.	MgO	P_2O_5	Insol.	MgO
Carbonate tail	10.7	7.7	6.0	6.8	3.0	8.9	58.3
-40 microns	4.8	21	19.3	1.7	3.7	12.9	6.4
Silica tail	3.3	15.5	43.2	1.1	1.9	19.9	3.0
Concentrate	81.2	31.0	5.2	0.5	91.5	58.3	32.3
Feed	100	27.5	7.2	1.3	100	100	100

Source: JESA Technologies

Summary

Flotation studies on a North African phosphate ore at JESA's pilot plant in Lakeland, Florida, have demonstrated that separating carbonate and silica in two different stages results in better flotation performance. Overall, the test results show that removing fines and slimes, using a separate carbonate flotation before silica flotation, improves phosphate recovery, reduces the carbonate content in the final product, as well as minimising problematic foaming. ■

Reference

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ERIEZ FLOTATION DIVISION

Column flotation of ultra-fine phosphate ore

Due to decreases in phosphate prices and the development of low-grade, finely liberated phosphate deposits, efforts are being made to maximize global phosphate recovery and grade within existing and prospective phosphate flotation circuits. Such improvements are essential when treating a low-grade ore where processing costs are highest, operating margins are lowest, and a near zero-waste approach is necessary.

Innovative Eriez Flotation Division (EFD) technology

Column flotation has been successfully adopted as a commercial mineral beneficiation technology due to its proven ability to improve ore separation performance and meet some of the above challenges. Typically, column flotation cells are capable of producing higher grade concentrates, with lower levels of impurities, compared to other types of flotation machines.

A key characteristic of column flotation cells is their ability to operate effectively while maintaining and washing a deep froth zone. Eriez Flotation Division (EFD) has developed its own proprietary industrial sparging system (Figure 1) for column flotation called the cavitation-tube (cav-tube for short). This improves fine particle recovery and maximizes the generation of bubble surface area.

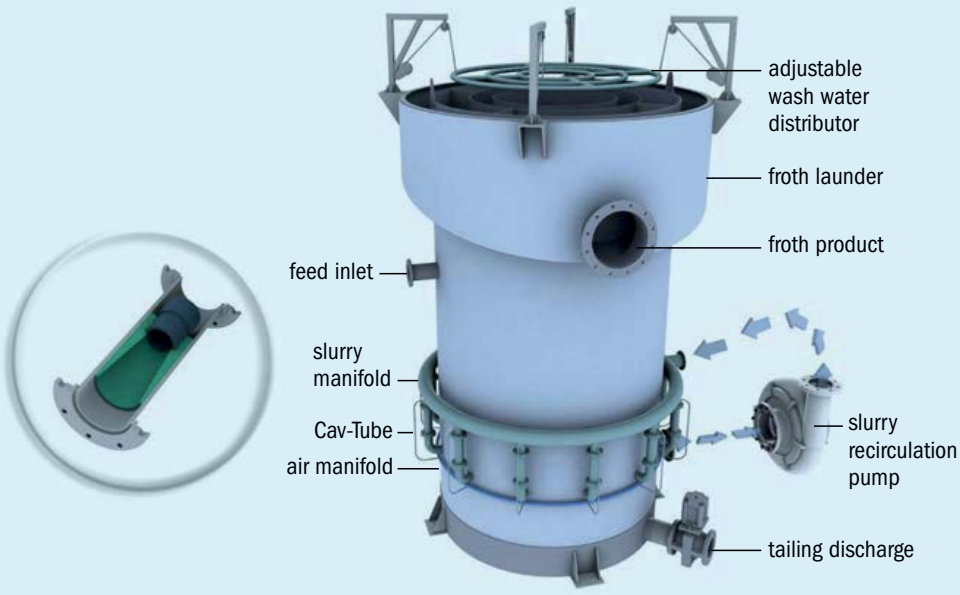
The cav-tube system operates by recycling a portion of column underflow slurry through one or more specially-designed bubble generators – known as cav-tube spargers – while air is also introduced to the system upstream of the sparger. This two-phase air/slurry mixture is then passed through the cav-tube spargers causing hydrodynamic cavitation to take place. Cavitation ensures maximum collection of particles by promoting two simultaneous mechanisms:

- The generation of tiny 'picobubbles' that adhere to the surfaces of hydrophobic minerals
- Intense mixing within the remaining slurry.

Case study: the Três Estradas project

The Três Estradas greenfield phosphate project is being developed by Aguia Resources (Aguia) in the state of Rio

Fig. 1: **Typical EFD column flotation cell with cavitation-tube sparging system**



Source: EFD

PHOTO: EFD

Column flotation array.

Grande do Sul in southern Brazil. Beneficiation trials with EFD column flotation technology have been an integral part of efforts to develop the project.

Initial bench-scale metallurgical test work on the Três Estradas ore indicated that a substantial portion of the apatite is contained in fine and ultra-fine fractions of the phosphate rock – and that, consequently, losses of apatite using conventional mechanical flotation machines could limit the commercial viability of the project. It was therefore concluded that column flotation should be considered for the Três Estradas project due to its inherent advantages over conventional flotation when treating fine and ultra-fine ores.

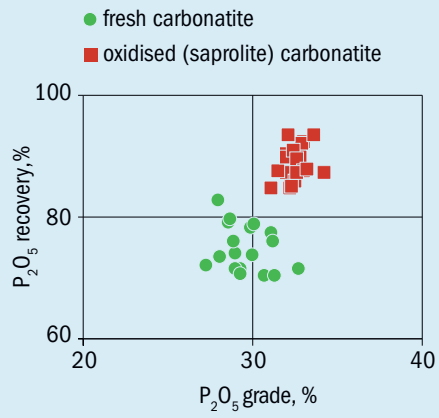
Using EFD's automated multi-stage column flotation circuit, a series of steady-state flotation tests were conducted to determine the flotation response of fresh carbonatite and oxidised carbonatite (saprolite) ore samples provided by Aguia. Nearly one-third of the phosphate content of the fresh carbonatite sample was contained in the minus 25-µm fraction, while one-quarter of the phosphate in the saprolite sample was contained in this fraction. For both samples, this meant recovery and selectivity of ultra-fines during the flotation process was extremely important for maximising the global phosphate recovery and grade. Results obtained for both samples, using a rougher-scavenger-cleaner-cleaner reverse flotation circuit, are discussed below and shown graphically in Figure 2.

Column flotation results for the fresh carbonatite ore:

- Sample upgraded from 3.6-4.1 percent P_2O_5 to 30-32 percent P_2O_5 – at a P_2O_5 recovery of 71-80 percent.
- Recovery increase of 2-3 percent, at equivalent concentrate grade, compared to results obtained by bench-scale mechanical flotation with five cleaning stages.
- Collector dosage requirement lowered from 600-800 g/t in bench-top mechanical flotation tests to 400-600 g/t in the steady-state column flotation tests.

Results for the oxidised carbonatite ore (saprolite):

Fig. 2: **Grade vs recovery for ultra-fine phosphate rock using an EFD column flotation circuit**



Source: EFD

- Sample upgraded from 10.0-11.5 percent P_2O_5 to 32-33 percent P_2O_5 – at a P_2O_5 recovery of 85-90 percent.
- Recovery increase of 5 percent, at equivalent concentrate grade, compared to results obtained by bench-scale mechanical flotation results obtained with three cleaning stages.
- Collector dosage requirement lowered from 800-1,200 g/t in bench-top mechanical flotation tests to 450 g/t in the steady-state column flotation tests.

In summary, test work with EFD's column flotation technology for the flotation of ultra-fine phosphate ores realised a number of distinct benefits. These included a higher degree of selectivity, increased recovery and reduced collector dosage, in comparison to bench-scale mechanical flotation cells. Specifically, column flotation increased phosphate recovery from fresh carbonatite and oxidised carbonatite ore (saprolite) by 2-3 percent and 5 percent, respectively, while collector dosage was reduced by 20-40 percent. At the same time, the required number of cleaning stages to achieve the target concentrate grade was reduced. ■

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ALLMINERAL

Pneumatic flotation: the breakthrough technology

Flotation technologies fall into one of three groups – mechanical, pneumatic and column flotation. Conventional Denver type mechanical flotation cells are currently the most well-established in phosphate processing plants worldwide.

The German company EKOF manufactured the first pneumatic cell for coal flotation in 1987. The innovative design incorporated an energy saving, self-aspirating, venturi-based aerator.

The *allflot*® pneumatic flotation machine from Düsseldorf-based manufacturer **Allmineral** (Figure 1) offers several potential benefits for phosphate ore flotation. It can either function as a scavenger cell to increases recovery and/or as a cleaner cell to improve grade.

The most important conditions necessary for pneumatic flotation are:

- Efficient reagent conditioning prior to flotation
- Creating the perfect size range and amount of air bubbles
- Efficiently attaching the air bubbles to mineral particles.

Fig. 1: **Allmineral's *allflot*® pneumatic flotation machine**

Source: Allmineral

Essentially, the *allflot*® machine behaves as a high-intensity flotation cell – with a flotation throughput 2-4 times greater than an equivalent mechanical flotation cell. The machine brings mineral particles into close contact with fine bubbles within an external aerator/contactor. The external contactor uses either pressurised air or air entrained in a fluid jet. The contactor/aerator functions as the primary collection zone while the main tank acts as the disengagement zone.

The *allflot*® machine's unique vertical pneumatic flotation design has been successfully demonstrated for coal, industrial minerals and other ore types. Phosphate flotation experience with the machine dates back to 1996 and includes detailed test work at JPMC in Jordan, Simplot in the US and Kazphosphate in Kazakhstan. Results demonstrated the ability of the *allflot*® machine to produce marketable phosphate grades and achieve high recoveries.

Allmineral designed a new froth channel discharge system for its pneumatic flotation machine in 2015. This allow both fine and coarse particles to be floated simultaneously.

To maximise efficiency during phosphate flotation, Allmineral recommends a flotation scheme that combines different flotation technologies. The company suggests the following two-stage scheme based on its operational experience:

- First stage: a rougher flotation stage using mechanical agitator banks/tank cells.
- Second stage: a scavenger stage using *allflot*® pneumatic machines.

Using *allflot*® machines as a scavenger cell in this way improves phosphate recovery by capturing and floating fine phosphate particles that would otherwise be lost by the turbulent rougher cell. (Conversely, when installed as a cleaner cell, *allflot*® technology is also able to deliver higher grade phosphate concentrates.)

The power consumption of *allflot*® pneumatic flotation cells are 40 percent lower than conventional mechanical agitator cells. Their installation footprint is also smaller. Furthermore, *allflot*® machines improve recovery and concentrate grade, as the flotation takes place without rotational parts and turbulence. Allmineral recommends a de-sliming hydrocyclone stage prior to flotation. Process water also needs to be cleaned using a thickener before being re-used in the flotation circuit. ■

Reference

Markworth, L., 2020. *allflot*® new challenges for phosphate flotation. *Procedia Engineering*. Forthcoming special issue: SYMPHOS 2019 – 5th International Symposium on Innovation and Technology in the Phosphate Industry.

NOURYON

Highly selective *Gemini* flotation collectors from Nouryon

Nouryon manufactures and markets a large portfolio of flotation reagents for the worldwide mining industry, including collectors for the flotation of calcite, iron, phosphate, potash, niobium, silicates, graphite and sulphide ores.

The company is a leading global provider of customised collectors for the phosphate flotation market. Nouryon's wide range of collectors are specifically tailored and optimised for different phosphate ore types (Table 1).

Complex ores are starting to dominate the mining industry due to the fast diminishing availability of high-quality rock deposits. The beneficiation of these complex ores requires advanced technologies. In response to this, Nouryon's research and development teams have worked intensively to develop highly sophisticated collectors for phosphate flotation – developing unique products and product blends able to deliver the required grade and recovery levels.

For phosphate ores containing only apatite and silicates, beneficiation using

Table 1: **Nouryon's flotation collector range for phosphate ores**

Ore type	Ore characteristics	Product name	Product composition/application
Igneous phosphates: direct flotation	Complex, difficult-to-float ores and/or hard process water	*Phospholan PE-65*	Boosters for complex difficult-to -float ores and/ or hard process water able to perform over a wide temperature range
		Phospholan PE-7	
		Berol 8305	Fatty acid special formulations
	Various ores	*Atrac 2600*	Synthetic anionic collector for improved selectivity
	High carbonate content	*Atrac 922, Berol 912*	Carbonate selective surfactants, proprietary formulation, primary collector
Sedimentary phosphates: reverse flotation	For use with a wide range of process water qualities	*Phospholan*	Low foaming phosphate esters for sedimentary phosphate
		Atrac 50N	Anionic collector for carbonate flotation from sedimentary phosphate
		Armoflote 465	Low toxicity cationic and readily biodegradable collector for silica removal
		Armoflote 763	Low toxicity and readily biodegradable quaternary ammonium collector for silica removal

Source: Nouryon

straightforward and proven technology is generally effective. The same is not true for more complex ores with high carbonate contents. Historically, obtaining high-quality phosphate concentrates from these difficult-to-process ores has been highly problematic. This is because traditional fatty acid collectors float apatite – also a calcium-bearing mineral – alongside calcite and dolomite, unless an effective depressant is available. However, following a recent breakthrough, Nouryon is now able to provide collectors which are highly selective for apatite only, so eliminating the need for a depressant.

Nouryon, in close collaboration with its customers around the world, is developing improved process reagents for phosphate producers, especially those applied in mineral beneficiation and flotation. Nouryon recently introduced the *Gemini* family of environmentally-friendly apatite collectors. These novel reagents are based on anionic surfactant technology and are effective collectors for the flotation of phosphate ores containing carbonaceous and/or siliceous gangue minerals. Compared to benchmark collectors currently used within the industry, Nouryon's *Gemini* range show outstanding selectivity towards apatite at a much lower dosage.

As a company, Nouryon is strongly committed to creating safer and more sustainable products. The *Gemini* family of novel apatite collectors, for example, combines high flotation performance and efficiency with high standards for product and environmental safety.

"To meet customers' challenging requirements, we are focusing on developing sustainable solutions for the mining industry," said Natalija Smolko Schwarzmayr, one of Nouryon's senior scientists in mining R&D. "We identify these as sustainable solutions due to the environmental profile of the surfactants and the improved efficiency and performance of our collectors." ■

Reference

Nouryon, 2020. Highly selective *Gemini* flotation collectors from Nouryon. Written for *Fertilizer International* March/April 2020.

A new sustainable framework for fertilizers

PHOTO: PHOSAGRO

PhosAgro's Cherepovets fertilizer production complex.

Concerns are growing about the health impacts of the heavy metals present in phosphate-based fertilizers and their accumulation in soils. In response, regulators and international agencies are currently seeking to limit human exposure to these potentially harmful elements. Encouragingly, a number of sustainable options with minimal market impacts are available, as **Mikhail Pleschev, Boris Levin** and **Juan von Gernet** of PhosAgro explain.

The fertilizer industry will need to change in the years ahead. Adapting to increasing consumer concerns about what goes into the food they eat will be a particular challenge. In response to this, regulators are starting to demand that fertilizers – as essential providers of crop nutrients – do not also introduce potentially harmful elements like cadmium and other heavy metals into soils and plants. Meeting this challenge is both necessary and possible, in our view, as everyone will benefit from the ultimate outcome – a more sustainable and healthier food production system.

The European Union (EU) has led the way by recently legislating to introduce limits on cadmium in phosphate fertilizers throughout the single market[1]. The UN's Food and Agriculture Organization (FAO) has also been active. It published a code of conduct for the sustainable use and management of fertilizers in 2019. This provides a framework for governments worldwide. Several countries globally are also considering placing limits on cadmium in fertilizers. Russia – the world's largest grain exporter – has taken a particularly innovative approach by developing legislation for the 'green' branding of products. This will include crops grown with 'pure' fertilizers.

The EU leads the way

The evolution of the EU's single market over the last decade has been extraordinary. In recent times, new EU-wide legislation has strengthened and harmonised regulation of one of the world's biggest markets. The most recent administration, under the leadership of European Commission President Jean-Claude Juncker, has acted to ensure that all EU legislation is both fit for purpose and reflects current market trends.

This has certainly been the EU's approach to fertilising products placed on the European single market. Previously, these were regulated by legislation dating back to 2003[2]. This had become increasingly outmoded as it did not take account of recent market changes and product innovations. Because of this, the European Commission came forward with a new set of proposed rules in 2016. The aim was to open the single European market to organic fertilizers and those sourced from bio-waste, while also strengthening sustainability and environmental protection. These proposals – officially approved in June 2019[1] – formed part of a wider and more ambitious circular economy policy package.

A key element of the EU's revised rules was the introduction of new limits on the cadmium (Cd) content of phosphate fertilizers. This was designed to reduce levels of this deleterious element to sustainable levels in European soils. A number of environmental and food safety agencies have determined that cadmium – which occurs naturally in some phosphate ores – poses a risk to crops and human health.

Under the new rules, the EU will introduce a harmonised limit of 60 mg Cd/Kg P_2O_5 from 2022[1].

The EU also approved a special labelling system that distinguishes low-cadmium products from those with a higher concentration of this heavy metal. The idea behind this is to increase transparency and awareness of the risks posed by Cd – so encouraging manufacturers and farmers to

pay attention to the cadmium content of the products they use.

The decision to limit cadmium was seen as a positive first step by many scientists. Nevertheless, experts from the European Food Safety Authority (EFSA)[3], the British Food Standard Agency (FSA)[4] and the French Agency for Food, Environmental and Occupational Health & Safety (ANSES)[5] have all said that even lower limits will be necessary to better protect humans and crops from cadmium exposure.

Environmental pressure groups, including Greenpeace and the European Environmental Bureau (EEB), have strongly argued against any cadmium limit above 20 mg Cd/Kg P_2O_5. Safer Phosphates – a business coalition committed to increasing awareness of the environmental risks posed by cadmium – has supported these efforts. Safer Phosphates accepts that the industry must act to reduce the Cd content of fertilizers, a major source of cadmium in arable land, as determined by the International Cadmium Association[6].

Although the EU's new rules will help protect the environment and prevent the contamination of arable land, it needs to go beyond the limits established in the EU fertilising products regulation in our view. Now is the time to be more ambitious by, for example, matching the stated ambitions of the EU *Farm to Fork Strategy*[7] with clear policies aimed at reducing contaminants in inorganic fertilizers.

Transparency and information must also be incorporated into future policies. This is vital if the risks from heavy metals in mineral and organo-mineral fertilizers are to be clearly described and communicated to the entire value chain. While concrete actions are necessary, education is also needed for all operators up and down the value chain – from farmers to retailers to producers.

A global framework from the FAO

We also believe that limiting levels of impurities in fertilizers requires a clear international regulatory framework. With this in mind, the code of conduct for the sustainable use and management of fertilizers published by the UN FAO in 2019[8] offers a useful framework in our view.

The code sets out voluntary guidelines relating to the production, trade, policy, regulation and use of mineral, organic and recycled fertilizers. It covers important aspects of agricultural sustainability, nutrient management and the safe use of agrochemicals.

The code – which is suitable for a wide range of stakeholders – was issued by the UN four years after the most recent edition of its international code of conduct on pesticide management[9]. Both codes complement one other, as they form two integral parts of the FAO's overall strategic objective to balance the demands of increasing food production with the conservation of natural resources.

According to the FAO, the aim of the new fertilizer code is to promote the efficient use of fertilizers, and address other key objectives such as:

- Global food security
- The preservation of ecosystems
- Reducing the negative impacts from excess nutrients in ground and surface waters
- Minimising the negative effects and potential toxicity from contaminants in fertilizers.

The last objective is particularly significant, since it places the negative effects associated with impurities in fertilizers on an equal footing with the harmful effects of pesticides and other environmental hazards.

While the code deals with a range of issues covering the whole life cycle of fertilizer products – including production, distribution, quality management and use – several provisions are specifically dedicated to the problem of contaminants found in fertilizers.

Firstly, the code stipulates that stakeholders should:

"Avoid additions of contaminants in fertilizers that have negative impacts on and potential toxicity to soil, soil biodiversity as well as animal and human health."

To achieve this, the code calls on governments to:

"Establish evidence based maximum limits for contaminants from fertilizers in soils (for example heavy metals), above which trade and use of fertilizer is controlled due to high probability of soil pollution."

In other words, policy makers should act to prevent the misuse of fertilizer that leads to the accumulation of contaminants in soils – i.e. they should ensure adequate soil fertility and nutrient supply while at the same time avoiding the take-up of undesirable compounds by crops.

In addition, the code suggests that governments and fertilizer producers need to take joint responsibility for:

"Regulating the composition and quality of fertilizers in terms of: nutrient content; heavy metals linked to the production process and source of raw material; harmful microbes; other dangerous or toxic materials."

The code also covers recycled nutrients. These include struvite, biochars, and incineration ashes – collectively referred to by the acronym STRUBIAS. It calls for appropriate guidelines and analytical procedures to control the level of heavy metals and other impurities in STRUBIAS prior to their use in plant production. Governments are also advised to minimise environmental effects from fertilizer application by providing training programmes to fertilizer users and retailers.

The code of conduct, being a framework document, provides a unified international set of standards and terminology covering fertilizer use throughout the world. As a next step, The Global Soil Partnership, a special division within the FAO – together with FAO member states and other stakeholders – will now translate this framework into a number of concrete actions and outputs to ensure safer fertilizer use in the coming decades. These are likely to include awareness-raising programmes and further guidelines and recommendations.

Heavy metals regulation beyond the EU

Regulation of heavy metals in phosphate-based fertilizers outside of the EU has been sporadic. This is most likely because of the complexity of the subject. Comparatively lenient limits are in place in Japan, Australia, New Zealand, Brazil and some US states, for example. However, a growing focus on long-term environmental sustainability is resulting in greater awareness and action. Recently, a handful of countries in Africa – a region seen as agriculture's next big growth prospect – have either introduced or are considering legislation to limit heavy metals in phosphate fertilizers. Russia, too, is taking a leading role.

In July 2019, the Russian Ministry of Agriculture presented a draft federal law: "On agricultural products, raw materials and foodstuff with improved environmental qualities." This draft legislation aims to create a unified vision for, and holistic approach to, the production and promotion of Russian goods for the domestic market and for export.

Are stricter cadmium limits possible?

The feasibility of limiting cadmium in phosphate fertilizers depends on three main factors:

- The quality of production raw materials
- The fertilizer manufacturing process
- The resulting level of cadmium exposure.

In our view, a brief analysis of each of these factors shows that even more ambitious limits on cadmium – as many are calling for in the EU – are fully within reach.

Processes and products

Most phosphate in fertilizers is sourced from phosphate rock. This raw material is a naturally-occurring ore mineral. It is generally extracted through open-pit mining and less frequently from underground mines. Phosphate rock contains other elements, in addition to the nutrient phosphorus, with their exact concentration depending on how the deposit was formed.

The most common way to produce phosphate fertilizers involves treating phosphate rock with sulphuric acid (acidulation) to produce phosphoric acid. This is generally reacted with ammonia to produce ammoniated phosphates. Acidulation yields calcium sulphate (phosphogypsum) as a by-product. This has little or no value in most markets and is usually discarded.

Other production routes also manufacture single super phosphate (SSP), nitrophosphate fertilizers and complex NPKs from phosphate rock. SSP production, although using sulphuric acid, yields a product with a lower nutrient content as no waste is discarded during the process. Nitrophosphates, which are produced using nitric acid, retain almost all of the impurities originally found in the phosphate rock.

The EU market – a case study

Given the recent introduction of new legislation, the EU makes a good case study for possible stricter cadmium limits in future. An analysis of production and trade data reveals that around 4-5 million tonnes of P_2O_5 in all forms was available for use across the EU-28 in 2016. (This figure includes phosphate rock, phosphoric acid, fertilizer, industrial and animal feed products, but does account for exports.) Roughly 40 percent originated from North and West Africa, 30 percent from the Former Soviet Union, with much of the remainder coming from either the EU itself or from the Middle East and South Africa.

By overlaying phosphate rock trade data with known heavy metals specifications – after accounting for the origin of the product and the manufacturing process – it is possible to estimate the amount of phosphate-derived cadmium. For 2016, the EU-28 average was found to be around 30-35 mg Cd/kg P_2O_5. This is in line with the European Commission's own estimate of 38 mg Cd/kg P_2O_5 for phosphate fertilizers, given that the commission's estimate excludes feed and industrial products. This analysis also shows that around 10 percent of the total phosphate available for use in the EU (and/or export) was in excess of the 60 mg Cd/kg P_2O_5 limit.

Even more striking is that only one country, Italy, was found to have an average cadmium content of around 60 mg Cd/kg P_2O_5 for its phosphate supply. Except for Italy, the EU countries with the highest cadmium exposure were Poland, Spain and France. In all three cases, the average cadmium content in their phosphate supply is estimated to be between 40-60 mg Cd/kg P_2O_5. This is explained by a combination of the large P_2O_5 requirement of these countries and the origin of their raw materials.

It is notable that all these countries can lower their average cadmium exposure significantly, simply by altering the source material for their phosphates. Poland, for example, showed elevated cadmium levels in 2016 because around a quarter of its P_2O_5 was sourced from phosphate rock mined in Algeria and Senegal. Although sourcing from these countries continues, recent Senegalese imports have been from a different mining region close to the Mauritanian border. These are said to contain much less cadmium (reportedly well below 20 mg Cd/Kg P_2O_5), thereby lowering the country's average substantially.

Conclusions

The above analysis suggests that, not only are the current limits adopted by the EU achievable, they can also be lowered further in future, if necessary. European industry has already shown that it can mitigate exposure to heavy metals by adjusting its sourcing, without having to alter production processes.

While opponents to the legislation regularly cite the limited availability of low-cadmium concentrates, such phosphate sources are in fact globally abundant in our view. Indeed, many have not even been properly mapped out, and hence are not included in current resource estimates. These include advanced low-cadmium rock projects in Africa, North America, Europe and Oceania which are still seeking financing currently. Their success will ultimately rest upon the ability to secure sufficient market demand for low-cadmium phosphate. ■

Importantly, the draft legislation distinguishes 'green' products as a separate market segment, distinct from either organic food or the mass market. These products are defined by six new national 'green' standards. Legislators, however, believe that compliance with these 'green' production standards will not create additional barriers for farmers. Instead, the aim is to ensure that farmers and food manufacturers receive a reliable supply of high quality inputs so that consumers will benefit from healthier food.

Two of these six new standards set out quality requirement for the fertilizers used in the production of 'green' products. Essentially, they establish and provide reference values for the purity of mineral fertilizers. Impressively, the limits introduced for some heavy metal contaminants are even stricter than the most stringent requirements of European countries, generally considered the most advanced in terms of environmental safety.

Switzerland, for example, adopted a cadmium content requirement of 21 mg/kg in 1986, and the harmonised EU

threshold approved this year is 60 mg / kg P_2O_5. These cadmium thresholds compare to the maximum limit of 20 mg/kg P_2O_5 being proposed under Russian legislation. In addition, the maximum level of arsenic – another harmful impurity present in some fertilizers – is half the value specified under EU Regulation (20 mg vs 40 mg per kg dry weight, respectively).

Despite these exacting purity criteria, the proposed Cd and As limits are feasible for the majority of Russian manufacturers of nitrogen, phosphate and potash fertilizers, without additional capital and operating costs, as their products already easily meet these limits. Consequently, those Russian farmers that use domestically-produced crop nutrients will gain the right to market their crop products as 'green' at no extra cost.

The proposed 'green' labelling should provide Russian agriculture with a distinct competitive advantage in global trade. Increasing awareness of the links between food quality, residual contaminants and sustainable soil management – as discussed in this article – should certainly boost international interest in high-quality, healthy Russian agricultural products.

Conclusion

Looking back, 2019 was a watershed year for the shift towards safer and more sustainable phosphate fertilizers – creating a momentum that is likely to grow in 2020 and beyond. As more countries seek to limit the heavy metal content of their crop nutrient products, the FAO's new code of conduct for fertilizers will provide a useful framework, while we will continue to monitor and learn from the real world examples set by the EU, Russia and others. ■

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