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Cover Story

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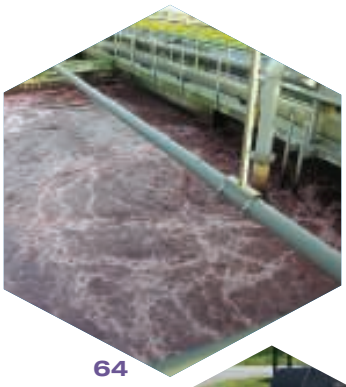
Technical and Practical



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Interfacing biology and engineering

When I was studying for my degrees in chemical engineering, I had the option to take several elective courses. Two that I chose were biochemical engineering and biomedical engineering. During the biomedical engineering course, I was fascinated with the ways in which the basic principles that I had learned in my chemical engineering classes could be put to use in medical devices, such as applying mass- and heat-transfer principles to dialysis equipment. Some of the lessons learned from the biochemical engineering course were put to use in a research project I worked on related to oxygen mass transfer in fermentation.

At the time, these were the only elective courses in bioengineering available. Since then, the department name of my alma mater has been changed from the Department of Chemical Engineering to the Department of Chemical and Biological Engineering. And, the university now (since 2010) also offers a degree in biomedical engineering.

Bioengineering

A look at academic curricula today reveals numerous programs that combine chemical engineering departments and biology, and many that also have distinct "bioengineering" departments. The University of California at Berkeley (www.berkeley.edu), for example, has a Department of Chemical and Biomolecular Engineering (CBE), as well as a Department of Bioengineering. Columbia University (New York; www.columbia.edu) lists both Chemical Engineering and Biomedical Engineering Departments. The National University of Singapore (www.nus.edu.sg) names a Department of Chemical and Biomolecular Engineering, as well as a Department of Biomedical Engineering in its offerings. And the list goes on.

It seems that some references to bioengineering equate it to biomedical engineering, while others use the term more broadly to include bioprocessing. Whatever terms are used, the integration of biology with engineering is a growing field, and its application in the chemical process industries (CPI) is expanding.

Application

In addition to well-known operations, such as beer brewing, fermentation processes have advanced to become viable options for producing chemicals that had traditionally been produced only via chemical routes.

A host of examples is given in Part 1 of this month's Cover Story — Harnessing Biotechnology: A Practical Guide (pp. 38–43). The same article concisely outlines principles that are important for successful industrial application of bioengineering.

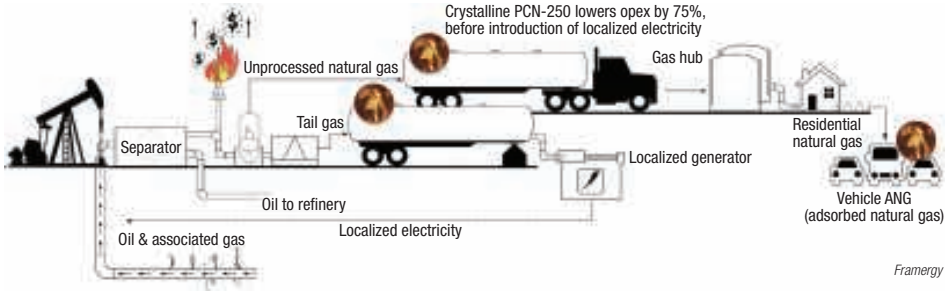
And, new advances in synthetic biology are opening the door to new possibilities for the manufacture of bio-based chemicals. You'll find insight into some of these developments in Part 2 of our Cover Story, Synthetic Biology for Chemical Production (pp. 44–49).

Biological processes other than fermentation have been in use in the CPI for quite some time. Treatment of wastewater by biological means, for example, is a well-established procedure. Some of the special considerations needed for the microorganisms are described in this month's article on Biological Wastewater Treatment (pp. 64–67).

We hope you enjoy reading these and the full selection of articles in this issue. ■

Dorothy Lozowski, Editor in Chief

MOF-based adsorbents promise to cut costs for capturing and storing flare gas



Framergy

A process for the separation and recovery of stranded and associated natural gas is being developed by Framergy, Inc. (Wilmington, Del.; www.framergy.com), with support from the National Science Foundation's Small Business Innovation Research (SBIR) Phase I program. The company is developing a reusable, transport-ready container to store gas at low pressure with a low-cost metal-organic-framework (MOF) adsorbent. This will eliminate the need for expensive gas-capture, purification and multi-stage compression systems in conventional methods, and will utilize gas that is normally flared.

Framergy's unique MOF material is composed of high-valence transition metal ions (such as Al^{+3}, Fe^{+3} and Cr^{+3}), which provide chemical stability under flare-gas conditions, while delivering high working capacity when used under pressure-swing cyclic operation, explains Koray Ozdemir, vice president and senior engineer at Framergy. The MOFs are based on the so-called PCN-250 (porous coordinated network), which was invented by Hong-Cai Zhou, professor of chemistry at Texas A&M University (College Station, Tex.; www.tamu.edu). The company's high-alkane adsorbed natural gas (trademarked, HAANG) technology further improves the MOFs' working capacity by alkane-based additives, which improves the adsorbed-natural-gas (ANG) performance to a level comparable to compressed-natural-gas (CNG) systems, says Ozdemir.

The gas storage pressure needed for Framergy's MOF-based system is 85% less than that required by CNG systems, which translates to lower capital (capex) and operational (opex) investment for upstream operators and service providers, says Ozdemir. "Framergy's ANG should reduce CNG capex by 10% and opex by 75%."

The company plans to test the technology at two oil wells in the Eagle Ford formation in Tex. and the Bakken formation in N.D. The first commercial application is anticipated for 2017.

A technique for making superhydrophobic metals

A scalable technology for allowing the cost-effective manufacture of superhydrophobic metallic coatings has been demonstrated in the laboratory. The method could have applications for heat exchangers, condensers, high-temperature and high-conductivity applications and other types of equipment.

The startup company Maxterial Inc. (Richmond, Calif.; www.maxterial.com) is working to commercialize the technology, which was originally conceived during the Ph.D. projects of Maxterial co-founders Mehdi Kargar and Atieh Haghdoost at Virginia Tech.

Maxterial uses a modified electroplating process to create micro- and nano-scale surface features on a variety of metals. Using a chemical bath equipped with positive and negative electrodes, the company can control the deposition of surface features. The resulting microtextured surface dramatically reduces the contact area for the objects and droplets that contact the metal surface, explains Kargar, so it repels water. "By controlling the components of the chemical bath and the manufacturing parameters, we can make surfaces with a variety of features," he adds.

A critical aspect of the technology is that it is designed to be integrated with existing manufacturing infrastructure, says Haghdoost. "This technology has a great potential for scaleup," she remarks.

Material scientists have demonstrated the technology using a variety of metals, including copper, zinc, nickel and chromium, and have characterized the surface structure. The company is now searching for strategic partners for custom-designing surfaces for specific applications.

Edited by:
Gerald Ondrey

Fe-FREE HTS CATALYST

Last month at the Nitrogen + Syngas 2016 conference (Berlin, Germany; February 29–March 3), Haldor Topsøe A/S (Lyngby, Denmark; www.topsoe.com) introduced SK-501 Flex, a new high-temperature shift (HTS) catalyst with the unique ability to operate at any steam-to-carbon ratio, allowing producers to achieve record plant efficiency in ammonia, hydrogen and synthesis gas (syngas) production.

"Producers get unique flexibility with SK-501 Flex, because it takes away the minimum steam-to-carbon requirement imposed by conventional HTS catalysts," says Johan Jönsson, product manager at Topsøe. Without changing production setup, the producer can choose to keep production at its current level, but save on feedstock and energy costs — or boost production by up to 5%. For a large-scale NH_3 plant, the improvement in revenue is approximately $11 million/yr, or $57 million over a typical catalyst lifetime," says Jönsson.

Instead of iron, the SK-501 Flex formulation is based on zinc oxide and zinc aluminum spinel that has been known to catalyze the water-gas shift reaction. The iron-free formulation of SK-501 Flex prevents formation of unwanted iron carbides that reduce the catalyst strength of conventional Fe-based HTS catalysts. Another major advantage of the new formulation is the complete absence of chromium, most notably the hazardous hexavalent chromium found in all iron-based HTS catalysts.

CATALYST GUARD

Also last month at the Nitrogen + Syngas 2016 conference (see above), Clariant

(Continues on p. 8)

Note: For more information, circle the 56-digit number on p. 94, or use the website designation.

(Muttenz, Switzerland; www.clariant.com) launched ShiftGuard 200, which effectively adsorbs and retains chlorides so that the downstream main low-temperature shift (LTS) catalyst is protected. Chloride is a typical catalyst poison in an ammonia or hydrogen plant that leads to an increasing and irreversible reduction of catalyst activity and mechanical stability. This can result in a significant catalyst lifetime reduction if Clariant's ShiftGuard 200 is not utilized.

In tests, ShiftGuard 200 demonstrated an "outstanding" chloride removal performance and a better mechanical and hydrothemal stability, as well as a high added low-temperature-CO shift activity with low methanol byproduct formation, says the company. ShiftGuard 200 is completely chromium free and therefore fullfills the criteria of a sustainable product by avoidance of critical metals.

UTILIZING CO_2

As part of the "Production Dreams" project, Covestro AG (Leverkusen, Germany; www.covestro.com) is working with RWTH Aachen University and the Technical University of Berlin on a process that will enable CO_2 to be used for making elastomers on an industrial scale. Elastomers are plastics that hold their shape, but are elastically formable. The German Federal Ministry of Education and Research (BMBF; Bonn, Germany) is providing funding for the project of up to €1.5 million over the next three years.

Elastomers are normally made entirely from petroleum. Now, some 25% of the oil used to manufacture a precursor can be replaced with CO_2. The resulting polyether carbonate polyurethane can be processed into elastomers. Individual batches of the new material have already been manufactured in the laboratory. Now, the focus is on developing a continuous process for industrial-scale production.

Covestro and its partners

(Continues on p. 10)

First commercial-scale gas fermenter in U.S. to break ground

Calysta

The first commercial-scale, natural-gas-fermentation facility in the U.S. will break ground by the end of 2016, according to Alan Shaw, CEO of Calysta Inc. (Menlo Park, Calif.; www.calysta.com). In a collaboration with agricultural giant Cargill Inc. (Minneapolis, Minn.; www.cargill.com), Calysta plans to build the facility in the U.S. to take advantage of inexpensive natural gas. The plant will eventually produce FeedKind Aqua protein, a sustainable and cost-competitive fish feed protein for use in aquaculture applications (photo).

FeedKind, designed as a sustainable alternative to replace fishmeal protein, will be produced from natural gas using strains of naturally occurring methanotrophs (methane-consuming bacteria) that were developed by Calysta to convert natural gas into high-protein biomass. The conversion process will employ a closed-loop reactor system for gas fermentation originally developed by Statoil ASA (Stavanger, Norway; www.statoil.com). The closed-loop reactor is designed to pressurize the gas within the fermentation media, speeding its dissolution into the liquid.

Calysta has previously demonstrated its methane-to-lactic-acid gas-fermentation process at smaller scales (see *Chem. Eng.*, August 2014, p. 15).

The new Cargill-Calysta facility will eventually have a capacity of 200,000 metric tons per year (m.t./yr) of FeedKind protein, which includes 72% crude protein, consisting of 18 amino acids, and 10% crude fat, Shaw remarks. Calysta also recently announced the construction of its Market Introduction Facility for FeedKind, a testing and development facility at the Center for Process Innovation in Teesside, U.K.

Recovering rhenium photochemically

Professor Hisao Hori and his research group at Kanagawa University (Hiratsuka City, Japan; www.kanagawa-u.ac.jp) have reported what is said to be the first photo-induced recovery of rhenium from aqueous solutions — an achievement with implications for an inexpensive way to recycle this rare earth element. The method has been shown to recover almost 95 wt.% of Re from solution — much higher than the 40–60% recovery achieved by conventional ammonia-based solvent-extraction — and the method is simpler than ion-exchange processes. And unlike solvent-extraction methods, the new process generates no nitrogen-containing wastewater.

Traditionally, rhenium is obtained by collecting perrhenate ions (ReO_4^-) in water from rhenium(VII) oxide (Re_2O_7) in molybdenite (molybdenum ore) roasting gas, then repeatedly recrystallizing it by means of heat concentration and cooling. The resulting precipitate is manufactured by igniting it in a H_2 stream, but since ReO_4^- salts are readily soluble in water across the entire pH range, the collection rate is low and the energy costs are high.

In the new process, 2-propanol and acetone is added to an aqueous solution containing ReO_4^- ions, and the solution simply irradiated with ultraviolet-visible (UV-VIS) light. The light causes a photo-induced electron transfer from 2-propanol (the e^- donor) to the ReO_4^-, which then precipitates as amorphous ReO_2 and ReO_3. The addition of acetone (also the product from the oxidation of the alcohol) was shown to reduce the induction time for the photochemical reaction from 19 h down to 6 h. The researchers believe the acetone forms a complex with the ReO_4^-, which enhances the absorption of light.

The method was shown to selectively recover rhenium from solutions containing both rhenium and molybdenum.

Optimized version of polymer additive raises PP clarity

Milliken & Co. (Spartanburg, S.C.; www.millikenchemical.com) has optimized its core clarifying technology for polypropylene (PP) resin to raise the clarity level to compete with that of polyethylene terephthalate (PET), polystyrene (PS) and polycarbonate (PC). The optimized technology allows the use of PP in food packaging and other applications where PP has not been used previously, because of haziness in the finished polymer.

"Milliken has been able to extend the technology behind its soluble, nonitol-based Millad NX 8000 additive to enable never-before-seen clarity and aesthetics," says Herrin Hood, global product line manager for Milliken's Millad NX clarifying additives. "In doing that, we have allowed users to access all of the benefits of PP in products that require the highest degree of clarity."

The advantages of UltraClear PP include better recyclability, heat-resistance and seal-ability than alternative polymers, such as polystyrene and PET. Also PP has a lower density, which allows the use of less plastic (with subsequent weight and energy savings) for the same performance, explains Emily Blair, Milliken's business development manager.

In addition to food packaging applications, where clarity of the package is a primary goal, the advanced clarifying technology is being used in medical and pharmaceutical applications, as well as food storage containers and others items, Blair says.

Engineering bacteria to tolerate higher temperatures

Vigorous microbial growth in bioreactors raises cell density, which is a source of heat stress and can hinder production efficiency. To address the issue, scientists have tried introducing genes for heat-shock proteins (HSPs) into workhorse industrial bacteria like *Escherichia coli*, but overexpression of those genes shuts down aspects of cell metabolism. A research team at the Beijing Institute of Technology (english.bit.edu.cn) has now developed a method for limiting bacterial density in bacterial strains equipped with HSP genes.

The researchers created a gene network in which a set of genes designed for limiting cell density is activated when the temperature exceeds a certain threshold. That set of genes is then linked to another set that triggers programmed cell death. The result is a strain that grows well at elevated temperatures, but that maintains a more constant cell density, thus limiting heat stress. The researchers' strain, called intelligent microbial heat-regulating engine (IMHeRE), showed the ability to produce five times more of the amino acid lysine (an animal-feed product) than a control strain of *E. coli* at the elevated temperature of 40°C.

have already shown that CO_2 can be used in the production of polyurethane flexible foam. The company is aiming to open the first production facility this year at its Dormagen site, where it will manufacture a polyol with a 20% CO_2 content as a precursor for flexible foams.

RARE MINERAL MADE

An international group of researchers, including those from Johnson Matthey (Royston, U.K.; www.matthey.com), has synthesized georgeite — an extremely rare mineral of the copper-hydroxycarbonate family. The mineral — which was synthesized using anti-solvent precipitation — was shown to exhibit improved catalytic activity, compared to industrial catalysts, for two important reactions: the water-gas shift reaction and methanol synthesis. The results are reported in a recent issue of *Nature*.

Partnership scales up the first ethylene-based metathesis process

A multi-company partnership has achieved the largest-ever use of molybdenum/tungsten (Schrock-type) catalysts for a metathesis process involving ethylene and renewable oils. The reaction run, which produced primarily 1-decene and 9-decenoic acid methyl ester from ethylene and plant oils, represented a scale-up by a factor of 40,000 over the laboratory demonstration. The products can be used for making a variety of bio-based specialty chemicals in several industries.

Olefin metathesis is a powerful synthetic technique that involves the exchange of alkene substituents through the breaking and reforming of carbon-carbon double bonds over specialized metal catalysts. In this case, a group of companies, including Elevance Renewable Sciences, Inc. (Woodridge, Ill.; www.elevance.com), XiMo AG (Lucerne, Switzerland; www.ximo-inc.com), Versalis (Rome, Italy; www.versalis.eni.com) and Soneas (Budapest, Hungary; www.soneas.com), was able to react ethylene with natural plant oils in a "second-generation" metathesis reaction that depends on Mo- and W-based catalyst systems designed and synthesized by XiMo using intellectual property from research by Amir Hoveyda at Boston College and Richard Schrock at MIT.

"These catalyst systems do not form stable complexes with ethylene, and thus are useful in reactions that either generate ethylene or react ethylene with another substrate," explains Mel Luetkens, chief operating officer at Elevance. The catalyst systems developed for this project operate at relatively low temperatures and pressures, affording low capital and environmental impact, Luetkens says. "Both catalyst systems can tolerate some functional groups in the metathesis reaction."

The scaleup was done at a Soneas manufacturing facility in Hungary. The companies plan to optimize the process and further scale it up. Elevance envisions that the ethylene-based metathesis process will complement the company's original metathesis chemistry involving 1-butene and natural oils. As the XiMo license is not limited to natural oil metathesis, these catalysts offer access to a wider portfolio of products.

A new catalyst may reduce costs of catalytic converters

Conventional catalytic converters in automobiles are based on heterogeneous catalyst systems with precious metals (such as Pt and Pd), rare earth elements and Ce (in the form of CeO_2). However, the cost and limited resources of such metals is driving efforts to find more sustainable alternatives. The group of Takeshi Fujita at Tohoku University (Sendai, Japan; www.tohoku.ac.jp), in collaboration with the National Institute for Materials Science (Tsukuba, Japan; www.nims.go.jp), has developed a durable catalyst system based on more abundant, less expensive elements.

The catalyst is made by a single step, whereby a NiCuMn alloy is treated with acid. This so-called "dealloying of Mn" activation process leads to a nanoporous NiCuMnO catalyst with a diameter of 50–100 nm. Microporous characterization shows a distinct structural feature in which catalytically active Cu/CuO regions are tangled with a stable, nanoporous NiMnO network.

The new catalyst exhibits good catalytic activity and durability for NO reduction and CO oxidation, showing high conversion at temperatures about 50°C lower than that required by existing Ni/Cu-based catalysts. The researchers demonstrated that the catalyst can produce CO_2, without generating NO and CO after a 10-day endurance experiment at 400°C.

Bio-based heat-transfer fluid for solar-thermal applications

A recently introduced heat-transfer fluid is made from corn sugar, rather than from petroleum. Known as So-Blu, the fluid was developed through a joint effort of Dupont Tate & Lyle Bio-Products (Loudon, Tenn.; www.duponttateandlyle.com) and SolarUS Inc. (Branford, Conn.; www.solarus.com), a producer of solar thermal energy equipment. The fluid is based on DuPont Tate & Lyle's bio-based 1,3 propanediol, known as Susterra, as opposed to petroleum-derived propylene glycol, which is used in conventional solar thermal systems.

According to Steve Elkin, CEO of SolarUS, the So-Blu product was designed specifically for the extreme temperature variations observed in modern solar-thermal energy systems. "So-Blu can withstand temperatures up to 350°F without breaking down, but also shows improved performance as an antifreeze," he says. Regular glycols start to form slush at –10°F, whereas So-Blu doesn't form slush until –30°F, Elkin notes. Also, Elkin says that while glycol products require stainless-steel and copper equipment, the So-Blu fluid can be used safely with aluminum and other alloys

The new bio-based heat-transfer fluid formulation also includes corrosion inhibitors and additives to decrease friction, thereby lowering energy required to pump the fluid. Although the fluid was designed for the solar thermal market, it can also be used in refrigeration systems, boilers, geothermal systems and cooling coils for ice-skating rinks, Elkin says.

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A new process to make olefins from syngas

Light olefins, such as ethylene and propylene, are primarily made by the catalytic cracking of crude oil. Alternatively, two other methods were developed during the time of high oil prices, both of which convert synthesis gas (syngas) to olefins: the methanol-to-olefins (MTO) process, which uses zeolite catalysts; and the (Fischer-Tropsch-to-olefins) (FTO) process, which uses metal catalysts. Although much progress has been made in direct syngas conversion to light olefins via Fischer-Tropsch synthesis, the wide product distribution remains a challenge, with a theoretical limit of only 58% for C2–C4 hydrocarbons. Now, professors Xiulian Pan and Xinhe Bao of the Dalian Institute of Chemical Physics of the Chinese Academy of Sciences (Dalian, China; www.dicp.ac.cn) have developed a third alternative, called the OX-ZEO (oxide-zeolite) technique. With this method, they report a $C2^{=}$–$C4^{=}$ selectivity of 80% and C2–C4 94% at carbon monoxide conversion of 17%.

The catalyst system consists of the partially reduced metal-oxide surface catalyst ZnCrOx, which activates CO and H_2, and C-C coupling and is subsequently manipulated within the confined acidic pores of zeolites. A zeolite called MSAPO is used to convert syngas to ketene (CH_2CO), and then into light olefins. OX-ZEO is highly selective, favoring the formation of propene. The catalyst also has a long lifetime (no deactivation was observed after 110 h), and carbon deposits, which can deactivate the catalyst, are not formed.

The researchers say their composite catalyst and the OX-ZEO process may allow the use of coal- and biomass-derived syngas, which has a low H_2-to-CO ratio.

Making H_2 and graphite from methane

Sydney University's Laboratory for Sustainable Technology (Sydney, Australia; www.sydney.edu.au) and the technology-commercialization-firm Hazer Group (Perth, Australia; www.hazergroup.com.au) are collaborating to scale up the Hazer Process, which uses an iron-ore catalyst to produce hydrogen and graphite from natural gas. Natural gas "cracking" — or thermo-catalytic decomposition of methane (TCDM) — has been a subject for research for many years, as a means of producing H_2 from natural gas, without also producing CO_2. The H_2 generated can be used as a feedstock for clean energy generation, either directly via fuel cells, or as a component of synthetic liquid-fuel technologies.

The key elements of the Hazer process are: a low cost, disposable catalyst, eliminating the need for re-activation and re-use, and enabling collection of the graphite produced; and the fact that the graphite produced is nano-structured carbon with a high degree of order and crystallinity, and is potentially valuable in global markets. During the cracking process, the graphite deposits on the surface of the catalyst, eventually reducing its activity. Since the catalyst is inexpensive, it is disposable, and the graphite can be harvested directly, with the catalyst remaining encapsulated as a minor impurity. ■

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Plant Watch

NET Power breaks ground on clean-power demonstration plant

March 10, 2016 — NET Power, LLC (Durham, N.C.; www.netpower.com) has broken ground on a first-of-a-kind 50-MW demonstration power plant in La Porte, Tex. NET Power's zero-emission Allam Cycle technology burns natural gas with oxygen, and uses the resulting CO_2 to drive a gas turbine.

KBR wins contract for restarted Kima fertilizer project in Egypt

March 9, 2016 — KBR, Inc. (Houston; www.kbr.com) has been awarded a new contract for proprietary equipment and has also restarted work under a contract awarded by Tecnimont S.p.A. (part of Maire Tecnimont Group), previously announced in December 2011, for the license and basic engineering design (BED) of a new 1,200 metric ton per day ammonia plant to be built by Chemical Industries Holding Co. in Aswan, Egypt.

KBR JV will project-manage refinery modernization in Baku

March 8, 2016 — Socar-KBR LLC has won a significant project management consultancy (PMC) contract for the Heydar Aliyev Baku oil refinery modernization project in Azerbaijan. The refinery capacity will increase from 6 to 7.5 million ton/yr. This is the first major award for Socar-KBR, a joint venture (JV) of KBR, Inc. (Houston; www.kbr.com) created in mid-2015 for oil and gas work in this region.

Multiple Algerian refinery contracts for Amec Foster Wheeler

March 8, 2016 — Amec Foster Wheeler (London, U.K.; www.amecfw.com) has been awarded a front-end engineering design (FEED) contract by Sonatrach SPA for three new refineries located in Biskra, Tiaret and Hassi Messaoud, Algeria. Each refinery will have a capacity of 5 million ton/yr of Algerian crude. Amec Foster Wheeler will also support Sonatrach in choosing technology licensors.

Johnson Matthey and Toyo awarded contracts for G2X Energy methanol plant

March 8, 2016 — G2X Energy, Inc. (Houston; www.g2xenergy.com) has signed license and engineering contracts with Johnson Matthey (London, U.K.; www.matthey.com) for a previously announced world-scale methanol production facility in Lake Charles, La. The Big Lake Fuels Methanol Plant will produce 1.4 million metric ton per year (m.t./yr). Toyo Engineering Corp. (Toyo; Chiba, www.toyo-eng.co.jp) will provide basic engineering for offsite and utility facilities and detailed engineering of the complete methanol facility.

Dupont to provide alkylation technology for new Dalian refinery

March 8, 2016 — Hengli Petrochemical Co. of Dalian, China, has awarded DuPont Clean Technologies (Overland Park, Kan.; www.cleantechnologies.dupont.com) a contract to supply its Stratco alkylation and MECS spent-acid regeneration (SAR) technologies for a new grassroots petroleum refinery in the Changxing Island Harbor Industrial Zone. Hengli will produce high-quality alkylate from a 100% isobutylene feed. Startup is planned for 2019.

Rare-earth metals pilot plant nears completion in Salt Lake City

March 7, 2016 — The SuperLig-One pilot plant for rare-earth metals in Salt Lake City, Utah is almost ready for commissioning, says owner Ucore Rare Metals Inc. (Bedford, Nova Scotia, Canada; www.ucore.com). The plant is being built by IBC Advanced Technologies (American Fork, Utah; www.ibcmrt.com) based on its own Molecular Recognition Technology (MRT) for high-yield recovery of valuable elements via organic ligands.

Evonik to double hollow-fiber membrane capacity in Austria

March 3, 2016 — Evonik Industries AG (Essen, Germany; www.evonik.com) will further expand its site in Lenzing/Schörfling, Austria, to double production capacity for Sepuran hollow-fiber membrane modules. The membranes are used to separate and purify gases, including biogas, hydrogen, helium and nitrogen.

Air Products to provide membranes for Shenhua Ningxia coal-to-liquids project

March 3, 2016 — Air Products' (Lehigh Valley, Pa.; www.airproducts.com) Prism Membranes division in Saint Louis, Missouri, has received a significant order for membrane separators for the Shenhua Ningxia Coal-to-Liquids Project in Ningxia, China. The membranes will be part of a hydrogen purification and recycling operation that is expected to start up later this year. They will process up to 280,000 standard cubic meters per hour of gas.

Mergers & Acquisitions

Covestro and Nanodax collaborate on polycarbonates with glass wool

March 8, 2016 — Covestro AG (Leverkusen, Germany; www.covestro.com) and Nanodax Co. (Tokyo, Japan) have signed an agreement on the development of innovative polycarbonate composites reinforced with glass wool, based on a process developed by Nanodax. Covestro is a leading polycarbonate supplier, and most of the work will take place at the company's Polymer Research & Development Center (PRDC) in Shanghai, China.

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Mitsui acquires a stake in Korean composites manufacturer
March 3, 2016 — Mitsui & Co. (Tokyo; www.mitsui.com) and Hankuk Carbon Co. (HC) have entered into a strategic alliance to collaborate on lightweight carbon-fiber composite materials for motor vehicles. Mitsui will acquire a 10% equity stake in HC for an investment of KRW 30.6 billion (approximately ¥2.8 billion). At the end of February, Mitsui said it would acquire 25% of Hexagon Composites ASA, a Norwegian manufacturer of pressure vessels made from composite materials.

Sumitomo to acquire stake in Brazil-based biofuels producer
March 2, 2016 — Sumitomo Corp. (Tokyo; www.sumitomo.co.jp) will acquire up to 20% of Cosan Biomassa S.A., a subsidiary of the world's largest sugar company Cosan S.A. Industria e Comercio, subject to anti-trust approval. Based in São Paulo, Brazil, Cosan Biomassa produces and distributes sugarcane biomass pellets for power generation. In December 2015, Cosan Biomassa started up a 175,000 m.t./yr pellet plant. "Brazil is positioned to become the Saudi Arabia of renewable energy," the company said.

Thai-Indian joint venture in PET manufacturing
February 29, 2016 — Indorama Ventures Public Ltd. (IVL; Bangkok, Thailand; www.indorama.net) and India's Dhunseri Petrochem Ltd. will enter into a joint venture (JV) to manufacture and sell polyethylene terephthalate (PET) resins. Dhunseri will purchase a 50% stake in IVL's 216,000-m.t./yr plant in Haryana, India. IVL, in turn, will acquire 50% of Dhunseri's 480,000 m.t./yr plant in West Bengal, India.

Axiall to sell compound additives assets to Galata Chemicals
February 29, 2016 — Axiall Corp. (Atlanta, Ga.; www.axiall.com) has signed an agreement to sell certain assets of its compound additives business, known as Solucor, and its manufacturing facility located in Bradford, Ontario, to Galata Chemicals (Southbury, Conn.; www.galatachemicals.com). The Bradford facility manufactures additives to improve the performance of rigid PVC. It has around 60 employees.

Industrial service providers Team and Furmanite to merge
February 26, 2016 — Team, Inc. (Houston; www.teaminc.com) and Furmanite Corp. (Houston; www.furmanite.com) announced that their stockholders had overwhelmingly approved a merger. Team Inc. provides inspection, assessment, and other services for high-temperature and high-pressure piping systems and vessels. Furmanite delivers a wide portfolio of industrial inspection and mechanical services.

GFBiochemicals enters U.S. market with acquisition of Segetis
February 19, 2016 — GFBiochemicals Ltd. (Milan, Italy; www.gfbiochemicals.com) will acquire Segetis (Golden Valley, Minn.; www.segetis.com), the main producer of levulinic-acid derivatives in the U.S. The deal is part of GFBiochemicals's strategic plan to establish a direct presence in the U.S. under GFBiochemicals Americas. Levulinic acid can replace crude oil as a building block for polymers. ■

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New Possibilities in Upstream Milk Processing

While thermal treatment remains king, new alternatives for processing milk are promising a number of benefits to the dairy industry

IN BRIEF

GEA Niro

FIGURE 1. Spray drying is widely used to form milk powders, which is one way to increase the shelf life and improve the ability to export milk products

The dairy industry faces a daunting challenge. It has to produce — at an affordable price — milk and milk products that are safe to consume, look good and taste good, and have a high nutritional value. Fresh milk is a highly perishable product with a relatively short shelf-life among farm products, so another challenge for the dairy farmers is to lengthen milk's shelf-life. The dairy industry also has to contend with increasingly stringent regulations regarding the safety of its products, its environmental performance, and the demands of animal-rights activists.

In addition to those challenges, the market has not been too kind to the industry. "The downturn in demand from China and Russia has resulted in an over supply of milk solids, therefore driving the prices down," says Maren Fiorelli, manager marketing & market intelligence at GEA Refrigeration Technologies GmbH (Düsseldorf, Germany; www.gea.com). "Meanwhile, farm production of liquid milk is increasing, therefore the demand for processing power is increasing (Figure 1). This mismatch means that dairy companies are reluctant to embark upon major investment projects while the world prices are so low, and must ensure that their existing plants work at their maximum production capacity," Fiorelli says. "This has led to the requirement for plants to be converted to running 24/7. There has also been an increased focus on specialty products (such as infant formula for China/Asia), which are less price sensitive."

The nature of milk

Milk is an extremely complex food, with components that are essential to human health, including proteins, lipids, lactose, vitamins and minerals. The lipids in milk are in the form of fat globules; the proteins are

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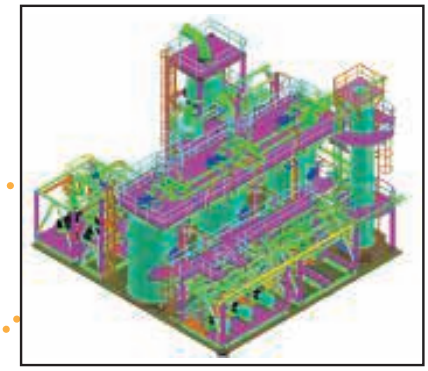

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Hielscher Ultrasonics

FIGURE 2. This ultrasound system can be used for the continuous processing of milk and other materials

present as micelles in the colloidal dispersion and in soluble form in the serum; the lactose and the minerals exist in solution.

Pasteurization

The first step in processing raw milk is usually pasteurization, intended to destroy the pathogenic bacteria in the milk and to provide an end product with extended shelf life. There are many milk-borne pathogens, including: *Escherichia coli*, which causes gastroenteritis and kidney failure, and even death; *Listeria monocytogenes*, which can cause flu-like symptoms and miscarriage; *Mycobacterium bovis*, which can cause tuberculosis; and *Salmonella* species, which can cause gastroenteritis and typhoid fever.

Those bacteria are destroyed by pasteurization. However, pasteurization entails serious drawbacks, such as denaturing and further changing in the form of the milk's proteins and decreasing its nutritional value. The heat treatment of pasteurization also affects the mineral balance, may destroy some of the vitamins, and may cause changes to the milk's color and flavor.

Therefore, many techniques have been explored to replace traditional pasteurization processing, and that would cause least damage to the milk's nutritional ingredients and provide longer shelf-life. Those alternative techniques include ultrasonic processing, high-pressure processing, pulsed electric fields, microwave heating, gamma rays and ultraviolet light. These alternatives have been developed to a high level and have been tested and validated.

However, overall the dairy industry has not yet incorporated these alternatives, partly due to the strict regulations that apply to the introduction of new technologies. A senior vice president of the U.S. National Milk Producers Federation (Arlington, Va; www.nmpf.org), Clay Detlefsen, says he believes none of those technologies are in commercial use yet. He says in the U.S., thermal pasteurization is the preferred treatment, which can be the traditional high-temperature, short-time (HTST) or ultra-high-temperature (UHT) treatments.

The standard HTST process leads to a 99.999% reduction in the number of bacteria in the milk, rendering it safe to drink for up to three weeks if continually refrigerated. The newer, UHT treatment, heats the milk to higher temperature for a shorter time. This extends the milk's shelf-life and allows the milk to be stored unrefrigerated because of the longer-lasting sterilization effect.

Detlefsen says the amount of information required by the U.S. Food and Drug Administration (FDA) for licensing the introduction of new technologies is formidable. That, in itself, limits the introduction of new technology into the market.

Ultrasound processing

While most dairy companies have not yet incorporated those new technologies, Kathrin Hielscher, project development manager of one of the suppliers of food-processing equipment, Hielscher Ultrasonics GmbH (Berlin, Germany; www.hielscher.com) says the company has sold a lot of equipment for various ultrasonic processes (Figure 2) in the dairy industry worldwide.

Uhde High Pressure Technologies

FIGURE 3. High-pressure processing is making inroads in preserving foods, but has not yet been adopted by the dairy industry

Ultrasound processing of food, particularly of dairy products, has been the subject of a large amount of research around the world, and it seems to be the most promising among the new non-thermal technologies under investigation. It presents advantages in that it is nontoxic and environmentally friendly compared with other technologies such as microwaves, gamma radiation and pulsed electric fields.

How it works. Ultrasound in liquids produces many effects, such as mechanical agitation, micro jets, shear forces, micro streaming, hot spots and shockwaves. It can produce the phenomenon of cavitation with the formation of microscopic bubbles. When these bubbles implode, there is a very rapid increase in the temperatures and pressures inside the imploding bubbles, creating extreme environments where a variety of chemical reactions take place, including the generation of highly reactive radicals.

All of those effects can be very useful. For example, low-end and high-intensity ultrasound of 20 kHz can kill bacteria. Extraction and emulsification processes use mainly the physical forces generated during acoustic cavitation. Reducing or oxidizing radicals are necessary to degrade organic pollutants in solution.

Skimming. Skimming and homogenizing can also be accomplished with ultrasound. Skimming is the crucial stage in the upstream processing of milk. It is the separation of the cream (fat) from raw milk. This is desirable because the cream is often sold separately as the raw material for products such as butter and yogurt, and because the cream contains saturated fat, which may be unhealthy for some people.

In the old days, the cream was separated from the milk by letting gravity do the trick, since cream is less dense than water and floats on it. Today the separation of the cream from the milk is usually accomplished rapidly in centrifugal cream separators.

Homogenization. Milk is often homogenized, a treatment that prevents a cream layer from separating out of the milk. The purpose of homogenization is to break down fat molecules in milk so that they resist separation. Without homogenization, fat molecules in milk will rise to the top and form a layer of cream. Homogenizing milk prevents this separation by breaking the molecules down to such a small size that they remain suspended evenly throughout the milk. The milk is pumped at

high pressures through very narrow tubes, breaking up the fat globules through turbulence and cavitation.

Homogenization leads to longer-shelf life for milk. It also makes it easier for dairies to filter out the fat and create 1% or 2% skim milk. You can have one of the two processes, pasteurization or homogenization. If both are undertaken, the milk is pasteurized immediately before or during homogenization, because homogenization may alter the milk's flavor if it is not done in conjunction with pasteurization.

A recent study by CSIRO Food and Nutrition (Melbourne, Australia; www.csiro.au), led by Maryanne Augustin, has used high frequency ultrasound (400 kHz and 1.6 MHz) for separating fat from milk. The basic concept here is the establishment of standing waves where the acoustic force can move fat particles to nodal planes where they coalesce to generate larger low-density particles that would float to the liquid's surface where they could be skimmed off. This process has the advantage that it does not require cavitation, avoiding the generation of radicals, and does not generate shear forces.

Other ultrasound applications. There are many other applications of ultrasound in further downstream processing. A team from the University of Melbourne (Melbourne, Australia; www.unimelb.edu.au), led by professors Muthupandian Ashokkumar and Sandra Kentish has achieved a significant breakthrough in producing whey protein concentrates by using ultrasound to lower the viscosity and improve the heat stability of those systems. "Transformation of the sulfur-containing proteins by the application of ultrasound may overcome many of the difficulties currently encountered in thermal processing of whole milk and whey proteins," says Ashokkumar.

High-pressure processing

Next to ultrasonic processing of foods, high-pressure processing (HPP) is another technique with great promise. This process subjects liquid and solid foods, with or without packaging, to pressures between 100 and 800 MPa.

Hiperbaric

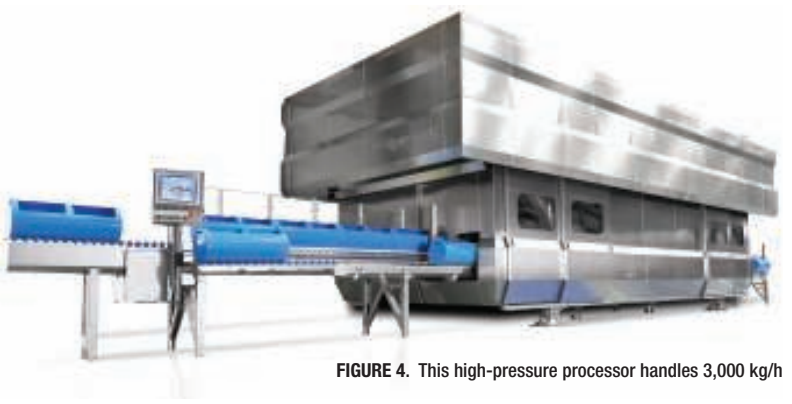

FIGURE 4. This high-pressure processor handles 3,000 kg/h

Vessels are designed to withstand those pressures over many cycles. Exposure times at pressure can range from a millisecond pulse to a treatment time of more than 20 min.

One of the most attractive features of HPP is its uniform processing ability. The pressure is applied uniformly throughout the food material, independently of its mass and of time. The advantage of HPP is that it not only homogenizes milk, but also inactivates the microorganisms and extends the shelf-life of the product, similarly to milk processed under ultra-high temperature conditions.

Studies revealed that high-pressure treatment inactivates the three major food pathogens: *Listeria monocytogenes, E. Coli,* and *Salmonella Enteritidis* when present in milk.

Contrary to thermal treatments, where covalent as well as non-covalent bonds are affected, high-pressure treatment at room and mild temperatures only disrupts relatively weak bonds (hydrogen bonds, hydrophobic bonds, ionic bonds). Thus, small molecules, such as vitamins, amino acids, simple sugars and flavor compounds, remain unaffected by the high-pressure treatment.

Although used in some areas of the food industry (Figure 3) and despite its advantages, HPP does not seem to have caught on with the dairy companies commercially. "Unfortunately in Germany there is no company using HPP on dairy products," says Boris Brockhaus, product manager HPP with Uhde High Pressure Technologies GmbH (Hagen, Germany; www.uhde-hpt.com).

HPP is used in food processing, other than milk processing, however. Hiperbaric SA (Burgos, Spain; www.hiperbaric.com), has just released its Hiperbaric 525 (Figure 4) which, the company claims, is the largest HPP system in the world. With a 525-L capacity and large 380-mm dia., the unit achieves throughputs of more than 3,000 kg/h of product. Hiperbaric has a partnership agreement with Fonterra Cooperative Group Limited (Auckland, New Zealand; www.fonterra.com).

Electric fields

Pulsed electric fields is another emerging non-thermal technology aimed at controlling microorganisms. Alexander Golberg of the Porter School of Environmental Studies at Tel Aviv University (Tel Aviv, Israel; www.tau.ac.il) has conducted a study to control the proliferation of *L. monocytogenes* bacteria in milk by intermittently delivered, pulsed electric fields (IDPEF). He designed an IDPEF system consisting of two sequences of 10 square-wave pulses, of 50-µs duration, 12.5-kV/cm electric-field strength, delivered at 0.5 Hz and 1 min pauses between the sequences applied every 1.5 h.

In a 12-h experiment, the bacteria density of samples treated with IDPEF remained about one order of magnitude below the initial values, whereas for untreated samples, the bacteria density increased by 2–5 orders of magnitude. Golberg says the energy required for IDPEF storage of milk in low-income countries could be generated by a small-scale, 2-kW solar-energy system operating 5.5 h/d in combination with a small-scale energy storage system. ■

Paul Grad

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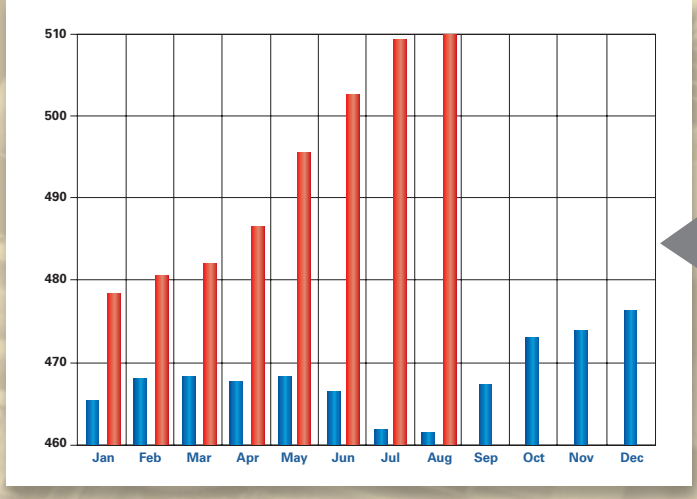

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IN BRIEF

Yokogawa

FIGURE 1. The TDLS8000 tunable-diode-laser spectrometer employs TruePeak technology, which can measure the area of the absorbance peak, eliminating effects from changing background gases and allowing for simple pressure and temperature compensation

Between process-control optimization initiatives and increased environmental monitoring requirements, the number of gas analyzers in chemical-process-industries (CPI) facilities is proliferating at a faster rate than plant analyzer budgets and manpower can accommodate, according to industry experts. At the same time, a lot of employees with analytical expertise are retiring, so the analyzer knowledge base is shrinking dramatically.

To combat these challenges, chemical processors are upgrading older, maintenance-intensive gas analyzers with newer measurement technologies that require less maintenance and fewer support utilities. In addition to reducing maintenance and costs, upgrading to smarter, easier-to-use gas analyzers can provide quantifiable process benefits.

"Higher-performing analyzers often provide better repeatability, increased speed of response and better accuracy, as well as lower levels of detection, which can lead to significant gains in advanced process-control algorithms that ultimately lead to tighter process control," says John Calame, product business manager for gas analytics, with Endress+Hauser (Houston; www.us.endress.com). "This tighter control drives improvements in product quality and reductions in off-specification product. These production improvements yield more sellable product at a lower cost and, therefore, higher profit margin."

"Processors want the data and speed that only a higher-performing instrument can provide, so that they can respond to those data swiftly and with confidence in an effort to improve their product quality and reduce their costs, which drives their business forward," explains Tracy Doane-Weiderman, marketing manager, analytics team lead for liquid and gas analytics with Endress+Hauser. "However, their focus is on their core business. They don't want to spend a lot of time or effort gathering those data and tending [to] analyzers."

For this reason, analyzers are becoming more robust so that they can withstand high temperature and corrosive environments, allowing them to be located closer to the measurement point. Placing the measurement device closer to the process measurement helps minimize sample transport time or, with some technologies, eliminate it completely, which results in faster, or realtime, measurements. The latest analyzers are also being developed to be more user-friendly, reduce maintenance time and cost, and provide flexibility.

Higher-performing analyzers

Some of the latest trends in the analytical world include optical techniques, such as tunable-diode-laser absorption spectroscopy (TDLAS) and Raman spectroscopy, which require very minimal support utilities. These technologies require very little or no consumables, such as carrier, fuel and calibration

Ametek Process Instruments

Figure 2. Model 888 sulfur-recovery tail-gas analyzer uses ultraviolet (UV) technology to accurately monitor the H_2S and SO_2 concentrations in sulfur recovery tail gas

gases, and they minimize or greatly reduce the need for sample systems. They can also operate unattended for long periods of time, and often feature automatic validation to provide positive proof that the analyzer is working properly, so the operators are sure the instrument is accurate and calibrated, therefore they don't dismiss alarms as nuisances.

TDL technology. TDL (tunable diode laser) technology has found applications in both process gas analytics and continuous emissions monitoring. The major benefit to this in-situ approach to gas analysis is that the measurement is performed non-intrusively and in realtime without any disturbance or delay to gas sampling or gas conditioning, says Warren Dean, strategic sales support for analytical products and solutions with Siemens Corp. (Alpharetta, Ga.; www.siemens.com).

In addition to accurate, realtime measurements, another major benefit is that the diode-laser measurement technology provides long-term stability through a built-in, maintenance-free reference gas cell, making field calibration unnecessary. "In many of the applications where TDLs are finding use, such as measuring ammonia in the stack, calibration is a nearly impossible task, but because these units have an internal calibration and internal reference cell, they don't need to be calibrated in the traditional hands-on method," says Dean.

Siemens' LDS 6 can measure up to two components, including oxygen, ammonia, hydrogen fluoride, water, carbon dioxide, carbon monoxide and hydrogen chloride, and is component-specific from 0–5 parts per million (ppm) to 0–5 vol.%.

Another benefit of the in-situ approach provided by TDL technology is that, because it is applied directly in the process, it eliminates the additional steps of sample take off and sample conditioning required by more traditional measurement methods, says Jesse Underwood, product manager for TDLS analyzers with Yokogawa (Sugar Land, Texas; www.yokogawa.com). "This provides faster, actionable information because it removes the time and associated costs required with an extractive sampling and conditioning system," explains Dale Cathey, analytical marketing

Thermo Fisher Scientific

FIGURE 3. The Prima PRO process mass spectrometer was developed to provide faster, more complete, laboratory-quality online gas composition analysis of multiple sample streams with different and varying compositions in each stream

manager with Yokogawa.

Yokogawa's TDLS8000 TDL spectrometer (Figure 1) employs the company's TruePeak technology, which can measure the area of the absorbance peak, eliminating effects from changing background gases and allowing for simple pressure and temperature compensation. And, its non-contacting sensor allows for use in corrosive, abrasive and condensing environments to measure O_2, CO, CH_4, NH_3, H_2O and more near-infrared absorbing gases. In addition, it offers a touchscreen and human-machine interface (HMI) to make it simple to operate and provide information, including trend graphing.

Raman spectroscopy. Another current laser-based technology is Raman spectroscopy. In this technology, the analyzer produces spectra that resemble and can be analyzed like chromatograms, but they don't require ovens, columns or use carrier gases. "The sensor itself is optically coupled via fiber-optic cables that go back to the base unit, so the technology doesn't require a typical extractive sample, which eliminates the potential for fugitive emissions and quickens the response time," explains Calame.

Endress+Hauser offers the Kaiser Optograf analyzer with Raman spectrography technology. This analyzer has multi-stream capability, with up to four probes per analyzer operating simultaneously, allowing up to four separate streams with multiple components per stream to be measured, as well as direct measurement of gas with a single analyzer. And, due to the fiber-optic coupling system, extensive extractive sample conditioning and sample transport infrastructure is minimized.

Ultraviolet (UV). UV analysis technologies also bring desirable features to the table, including increased reliability and advanced diagnostics that reduce maintenance requirements in demanding applications, such as tail-gas analysis, says Randy Hauer, product manager for sulfur recovery analyzers with Ametek Process Instruments (Pittsburgh, Pa.; www.ametekpi.com). For example, the

company's Model 888 sulfur-recovery tail-gas analyzer (Figure 2) uses UV technology to accurately monitor the H_2S and SO_2 concentrations in sulfur-recovery tail-gas. Model 888 provides reliability via automatic flow control for proactive response to adverse process conditions and flange temperature alarms for early warning of poor-quality steam, while smart diagnostic models identify, communicate and react to potential problems, which helps reduce unscheduled downtime.

Mass spectroscopy. Some of the latest, non-optical technologies also bring faster response times, increased reliability and flexibility to the table, notes Daniel Merriman, product manager for process analyzers with Thermo Fisher Scientific (Waltham, Mass.; thermofisher.com). "Some of the optical spectroscopy methods and lasers don't support all of the applications that conventional process gas analyzers can," he says. "Lasers tend to provide discrete measurements, but there are applications where multi-component measurements are required in different sample streams."

For these applications, he says, being able to measure multiple streams with different gas compositions provides valuable and cost effective data at process control levels. However, even in these applications, processors are still seeking higher speeds. "Process mass spectrometers are generally capable of measuring complex gas-sample streams within cycle times that are ten to twenty times faster than traditional gas chromatographs," says Merriman. "They are also largely configured by software so they are able to provide gas analysis from multiple sample streams where the gas composition might vary significantly between streams. Some of the processes being controlled are very dynamic so they benefit from fast gas analysis. That enables process control models to improve efficiency for the process that can yield increased productivity and reduced waste, resulting in reduced rework, reduced use of raw materials and lower energy costs. That's really where the value proposition of these advanced technologies lies."

Emerson Process Management

FIGURE 4. Gas chromatograph software control of a gas chromatograph is easier with intuitive, Windows-based pulldown menus and fill-in-the-blank tables. The software collects and organizes the analyzed data from gas chromatographs, such as the 700XA model shown here

The Thermo Scientific Prima PRO process mass spectrometer (Figure 3) was developed to provide faster, more complete, laboratory-quality online gas-composition analysis of multiple sample streams with different and varying compositions in each stream. The Prima PRO typically operates up to 90 days between calibration intervals, and it offers a fault-tolerant design for availability of greater than 99.7% to facilitate ongoing operation and enhance productivity.

Improving gas chromatography

"While we are seeing requests for inline instruments and instantaneous measurements, there are certainly some obstacles to overcome with spectroscopy over gas chromatography," notes Yokogawa's Cathey. "Gas chromatography is extremely accurate because it measures the components directly, whereas spectrography provides an inferential measurement based upon the optical properties of what it is measuring. So, there are some cases where there are very good solutions for spectrometers right now, but they tend to be application-specific. What this means is that the gas chromatograph is still a very viable technology for large numbers of applications."

Siemen's Dean agrees: "Laser and other analysis technologies are not taking over the analysis market. So, for this reason, we are also working to improve our traditional gas-chromatograph technologies."

He says a lot of effort has been made to improve reliability, stability and to include diagnostic systems that will recognize an issue or a potential problem. "There are now smarter sampling systems that can recognize issues like higher pressure differentials and that can constantly verify and validate measurements, as well as recognize when maintenance is needed," says Dean.

In addition to these smarter systems, providers of gas chromatographs are working on ease of use and simplified maintenance, says Bonnie Crossland, product marketing manager for gas chromatographs with Emerson Process Management's Rosemount Analytical (Irvine, Calif.; www.emersonprocess.com). "Gas chromatographs have never been viewed as an easy-to-use instrument," she says. "So we are starting to work on ease-of-use with features like interactive and intuitive touchscreens and we now offer advanced diagnostics so the machine itself provides feedback and suggests preventative maintenance to correct problems before measurement errors occur."

For example Emerson's MON2020 gas chromatograph software makes

configuration, maintenance, monitoring and control of a gas chromatograph easier with intuitive, Windows-based pulldown menus and fill-in-the-blank tables. The software collects and organizes the analyzed data from the company's 700XA (Figure 4) and 1500XA gas chromatographs and gives management, operators, engineers and maintenance personnel access to critical data, such as current and archived chromatograms, alarm history, event logs and maintenance logs. It also allows users to check original calibration against last calibration and to perform operations checks and modifications simultaneously.

"It allows users to get really specific and improve efficiency because they can get faster, more accurate results and adjust the process as needed based on the data, which results in more efficiency and less waste," says Crossland. "It helps you make more of what you want to make and less of what you don't and, because it is so intuitive and user friendly, you can accomplish this with fewer skilled experts."

Providers of gas chromatographs also realized the maintenance process, too, needed simplification, so they are beginning to offer modular systems. Siemen's MAXUM GC analysis platform offers a modular oven option, which is an airless oven design where complete chromatograph modules are snapped into place. Removal and replacement of a module can be performed in minutes, lowering operation and maintenance of the gas chromatograph. The module can then be repaired at the user's convenience in their maintenance shop or returned for refurbishment.

Experts agree that it is more than likely that the improvements to gas chromatographs and other analyzers make upgrading a facility's current technology worthwhile in terms of faster results, reduced maintenance time and costs, as well as improved process and product quality. "If processors haven't looked at the newer technologies in the last five years and considered an upgrade, they should certainly give it a look," says Crossland. ■

Joy LePree

Focus on Industrial Hygiene

This hood captures unwanted fumes from work spaces

The Purair Advanced P20 Ductless Fume Hood (photo) is designed to protect workplace operators from hazardous substances. It provides a face velocity of 100 ft/min to contain fumes. The unit is 49-in. wide, by 27.5-in. deep, by 47.5-in. high. Other sizes are available up to 96 in. wide. The primary filter can be chosen from 14 different types of carbon, including specialty media that is designed to remove vapors of organic compounds, solvents, acids, mercury and formaldehyde. HEPA filters for the removal of particulate solids are also available, to suit specific application needs. The Purair can also be equipped with a secondary backup filter to meet ANSI Z9.5 section 4.12 4.2 requirements. An alarm alerts operators when the airflow falls to an unacceptable level. Switches and electrical components are isolated from the contaminated airflow. The work area has a removable, cleanable spillage tray. Optional integral lighting is available. — *Air Science USA, Fort Meyers, Fla.*
www.airscience.com

Mezzanine gate reduces the risk of worker falls and injuries

The Protect-O-Gate Pivot Gate (photo) can be customized to accommodate various configurations. The pivot gate eliminates the potential for falls and other accidents often associated with mezzanine loading areas. The unit is counter-balanced and operator-friendly, says the company, to provide easy access to staging areas. Unlike conventional devices, such as chains, lift-out gates and sliding gates, this pivot gate cannot be bypassed. When the enclosure closest to the edge of the mezzanine is lifted to allow load delivery, the second enclosure rests on the mezzanine, protecting personnel from potential falls. Custom sizing is available, with optional increased loading height available to 80 in. Any dimensions can be modified to meet your specifications. The unit is shipped assembled, so it can be bolted to the mezzanine floor and put into operation immediately. — *Benko Products, Sheffield Village, Ohio*
www.benkoproducts.com

These absorbent products help ensure workplace safety

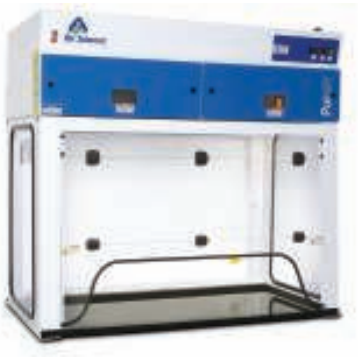
The eco-friendly Oil Eater Naturals line of absorbent pads, rolls and socks (photo) is available to help facility personnel respond to spills and leaks in the workplace — anywhere drips or spills can cause slippery conditions. The product line is made from natural plant byproducts and has woven construction. Oil-Only pads and rolls soak up oil and repel water. Universal Pads and Rolls soak up oil, water and other liquids. Absorbent socks are available to contain larger spills and protect drains. All come in various weights, finishes and sizes. — *Kafko International, Skokie, Ill.*
www.oileater.com

Electrical enclosures can be modified to add height

This company's standard 72-in.-tall cabinets and enclosures (photo) can be customized to a height of 90-in., to meet user requirements, when floor space is limited but vertical space is available. The company has modified its two-door, floor-standing 1422 and HN4FM series, and the single-door free-standing 1418 and HN4FS series (to 90-in. height), all of which are available in either painted mild steel, or 304 or 316L stainless steel construction. When used to house control or electrical equipment, the larger surface area of the taller metal cabinets also improves conduction, which can help to reduce cooling needs and thus reduce energy use. — *Hammond Manufacturing Co., Cheektowaga, N.Y.*
www.hammondmfg.com

This small-scale workstation captures fumes

The MicroFlow II is a small-scale, Class 1 ductless carbon-filtered



Air Science USA

Benko Products

Kafko International

Hammond Manufacturing

Note: For more information, circle the 3-digit number on p. 94, or use the website designation.

Hemco

workstation (photo). It is designed for general chemistry applications involving the handling of small volumes of chemicals, such as solvent cleaning of electronic parts, tissue staining and processing, gluing and drying operations, soldering applications, and more. It is equipped with activated carbon filtration, to capture fumes, odors and non-hazardous chemical vapors. It is completely self-contained with an integral, recessed work surface to contain spills. Variable-speed fan control allows for high-speed 100-ft/min air flow through the sash. A light indicates when it is time to replace the filter. — *Hemco, Independence, Mo.*
www.hemcocorp.com

ES2 Warning Signals

Surveillance camera provides exended Wi-Fi range

The Apollo Pro Camera allows facility managers to maintain surveillance, to monitor day-to-day operations for workplace safety, quality control, theft prevention and remote monitoring. Its long-range capabilities provide three times the Wi-Fi range of other competing cameras, says the company, and this allows operators to carry out security surveillance coverage in places never before possible. The Apollo Pro is equipped with a wide viewing angle, and advanced night vision capabilities provide clear viewing in dark conditions. A free app allows users to set up, view, listen, talk to, control and edit all of their Apollo Cameras from any device. — *Amped Wireless, Chino Hills, Calif.*
www.ampedwireless.com

Hospeco

Xenon strobe beacons have multiple configuration options

To complement its GNEx family of alarm horn sounders, loud speakers and manual call points for activation of fire alarms, gas detection and emergency-shutdown systems, this maker of audible and visual warning signals now offers the BNEx GRP Xenon strobe beacons (photo). Suitable for all Zone 1, 2, 21 and 22 hazardous location applications, the explosion-proof and corrosion-resistant GNEx beacons have extended temperature range with IECEx ad ATEX Ex d approvals. For signaling in applications with high ambient light, or for long-distance signaling, the GNExB2 beacon is available in 10, 15 and 21-Joule variants, producing a very high output Xenon strobe. Both 15- and 21-Joule versions can be supplied with a plate-mounted assembly configured with up to four xenon strobe beacons with a junction box, or five beacons without a junction box. — *ES2 Warning Signals, Houston*
www.e2s.com

Response kits help personnel deal with industrial spills

The TaskBrand Spill Kits (photo) are available to help plant personnel respond immediately to liquid spills, leaks or discharge of hazardous chemicals. The kits can be configured to contain different types of spill-response products, so they are ready for potential scenarios that could occur in different areas of the plant. For example, kits are available for universal spill types, for oil-only spill types, and for chemical applications. The TaskBrand kits come in 5-, 20-, 30-, and 65-gal capacities, and include gloves, safety goggles, a reusable bucket or laboratory pack/overpack, and the appropriate number of socks, pads and can liners to allow plant personnel to respond to spills. A vehicle spill kit is also available, consisting of two pads, two sorbent socks, and two clean-up bags. — *Hospeco, Cleveland, Ohio*
www.hospeco.com

Low-profile LED light fixture is rated for 100,000 h of service

The HAL-LED-CPR-40 is a 40-W, low-profile, LED light fixture that is approved for Class 1, Division 2 hazardous locations, while also carrying an ATEX Zone 1 and 2, as well as PSE and SAA certifications. It is said to provide a powerful and energy-efficient alternative to metal halide luminaries. This hazardous-area light fixture provides 4,000 lumens of light, while drawing only 40 W of power. It is constructed of durable, die-cast aluminum and comes with a tempered-glass lens that provides protection for the 24 individual LEDs that deliver high-quality light in a 120-deg beam spread. — *Larson Electronics, Kemp, Tex.*
www.larsonelectronics.com

Ultrasonic bath cleans large and small items concurrently

The Ultra 3200FA is an ultrasonic cleaner with 65-gal capacity that is

designed to handle both large and small parts simultaneously. The unit features an agitation table, dual filtration capabilities, a 10-gal weir tank, sparge bar and an insulated tank and lid. It includes side-mounted transducers that are said to eliminate "dead spots" and ensure consistent cleaning from top to bottom. The 3200FA operates at 220 V and draws 30 A. Digital touch controls provide for easy operation for facility personnel, and automatic control of ultrasonic cleaning, agitation and filtration. — *UltraSonic LLC, Cincinnati, Ohio*
www.ultrasonicllc.com

Slip-proof shoe coverings protect plant personnel

Kimtech Pure A8 Unitrax Shoe Covers (photo) provide traction and slip resistance, to prevent slip-and-fall injuries. The non-skid design provides four times more grip than competing products, says the company, and features seamless bottoms for better comfort. Three sizes are available, and they produce little or no lint, which reduces the chances of contamination. The company operates a recycling program to help divert used Unitrax shoe covers (as well as other types of non-hazardous laboratory and cleanroom garments and gloves) from landfills, converting the waste into raw materials to create eco-friendly consumer products and durable goods instead. — *Kimberly-Clark Professional, Roswell, Ga.*
www.kcprofessional.com

Prevent potential oil and fuel drips from reaching the ground

The weighted Pig Outdoor Drip Pad system (photo) is designed to capture and collect oil and fuel leaks and drips from vehicles, machinery, tanks and other equipment that is stored outdoors. The system is easy to deploy and can be staked into the ground to ensure that it remains in place, even in the face of windy outdoor conditions. The absorbent mat pads repel water and resist ultravioletlight damage for up to 12 months. The non-absorbent polyvinyl chloride (PVC) pad holder prevents any collected materials from soaking through to the ground. Grommets and a strap make it easy to retrieve the drip pad once the job is done. This product helps facilities to remain in compliance with 40CFR112.7 and 40CFR122.26. — *New Pig Corp., Tipton, Pa.*
www.newpig.com

Transfer loads easily with less bending and lifting

The LNB-2 (photo) combines the convenience and maneuverability of a two-wheel hand truck with the utility of powered lifting. With the touch of a button, the LNB-2's powered, adjustable-height platform positions loads at a comfortable height, to help reduce bending and stretching when loading, unloading or moving items from one level to another. Built on a lightweight, durable aluminum frame, the LNB-2 is easily maneuvered and can lift 200-lb loads o a height of 37 in. off the ground. The lift mechanism uses a timing-belt drive that is very quiet, according to the company, and it lifts loads at a speed of 4 in./s. Two rechargeable 12-V batteries provide the power. This product raises productivity, as many tasks that formerly required two workers can now be accomplished by just one person, says the company. — *LiftNBuddy, Fargo, N.D.*
www.liftnbuddy.com

Powered pallet truck offer precise positioning control

The PowerJak Electric Pallet Truck (photo) features powered lift and drive capabilities, for the safe and effortless transport of palletized loads. Two models are available with load capacities of 3,000 lb and 4,500 lb. This product features heavy-duty reinforced forks, which have a lowered height of 3.4 in. and a raised height of up to 8 in. The outside dimension of the forks is 27 in. and the load center is 24 in. An ergonomically designed handle puts all controls within easy reach, ensuring operator comfort and ease of operation. Forward- and reverse-drive switches are located on both sides of the handle to accommodate left- and right-hand operation. The unit can reduce drive speed by 50% for precise positioning control when working in tight quarters. Power is provided by two 12-V d.c., 75A-h, maintenance-free batteries. An onboard charger is also included.— *Presto Lifts, Norton, Mass.*
www.prestolifts.com ■

Suzanne Shelley

Kimberly-Clark Professional

New Pig Corp.

LiftNBuddy

Presto Lifts

New Products

Camfil APC

Dust-collecting filters that are flame retardant and conductive

The new HemiPleat FR Carbon dust-collector filter (photo) combines flame-retardant and conductive properties in a single filter. With high efficiency and a long service life, the cartridge filters are especially suited for explosive-dust applications, making it possible to conform to NFPA and ATEX requirements and lessen the risk of ignition sources due to static-electricity charges. The special carbon-impregnated filtration media is designed for dust-handling applications that require flame resistance and the dissipation of static charges. These include metal dusts, fumed silica, plastic or composite dusts, carbon black and more. The combined functionality of flame-resistance and conductivity can allow the use of dry-media-type dust collectors in applications where they otherwise could not have been used. — *Camfil Air Pollution Control (APC), Jonesboro, Ark.*

www.camfilapc.com

ABB

This flowmeter automatically synchronizes calibration data

The FCB400 (photo) is the latest expansion in the CoriolisMaster product range of mass flowmeters. A new standard-electronics platform offers users up to five configurable communication outputs via optional plug-in modules, and the entirely digital internal-communication system requires no special cabling. The FCB400 flowmeter saves all calibration data, as well as all user-configuration data and totalizers, which are linked to the sensor in a non-detachable way. This automatic function synchronizes configuration data in the sensor and the transmitter after power has been switched on. It duplicates configuration data, storing it in a permanent memory, ensuring data synchronization during maintenance. Many specific software packages are available for applications such as filling, density-based concentration determination and more. The FCB400 model is optionally available in a hygienic model, the FCH400, for use in the food and beverage industry. — *ABB, Zurich, Switzerland*

www.abb.com/measurement

Hardy Process Solutions

Modular, electronic pressure compensation for feeders

This company has introduced a new Electronic Pressure Compensation (EPC) system for high-accuracy loss-in-weight feeders. Improvements to the system include higher accuracy and reliability when compared with traditional mechanical pressure-compensation systems, which can be sensitive to structural factors and machine alignment, making them potentially more intricate and unreliable. The EPC system's modular design incorporates pressure sensors and electronics that are tailored to interact with the feeder-control system. Depending on system configuration, the sensors can be positioned on the feeder hopper, and if required, on the material-discharge tube. The integrated software implements a self-optimizing compensation algorithm, which ensures accuracy, even in systems with pressure fluctuations. — *Coperion K-Tron, Sewell, N.J.*

www.k-tron.com

This weight processor boasts fast PLC communications

The HI 6500-XP Extreme Weight Processor (photo) is an EtherNet/IP-enabled weight processor that can process and output 300 updates per second of processed stable weight. The processor's fast communication with the process logic controller (PLC) allows for higher product yield and consistency, while reducing processing time, says the company. The device is intended for applications where speed and accuracy are critical, such as batching, blending, filling, dispensing and check-weighing. With an embedded Web server, the instrument can be accessed remotely on any computer browser. — *Hardy Process Solutions, Inc., San Diego, Calif.*

www.hardysolutions.com

New graphics engine introduced with this software's recent release

In March, this company released Version 7.0 of its ChemCad process-simulation software. Featuring a new graphics engine, updates to the software suite include enhanced flowsheets at any zoom level, and three

new display schemes for unit operations — color, grayscale and wireframe — each of which can be used in any combination on flowsheets. According to the company, building flowsheets has been made more intuitive, and increased customization for reporting is available. Additionally, graphics options in Version 7.0 conform to standards set by other commonly used software tools. — *Chemstations, Inc., Houston*
www.chemstations.com

A two-layer rupture disc with a long service life

KUB reverse-acting buckling-pin rupture discs (photo) are well suited for use with pressure equipment, such as reactors, tanks, pipework, gas cylinders and pressure vessels. The KUB requires no torqueing, allowing for the disc to be periodically examined and placed back into its holder — a new disc is not required until the current one ruptures or is damaged. When the disc ruptures, no metal debris is cast downstream into the exhaust piping. The KUB's two-layered design increases longevity because the burst element is protected from potentially corrosive process media. The "domed" side contains precisely laser-cut buckling pins to ensure a precise response to pressure, and the second smooth layer isolates and protects the burst element from the process, resulting in a longer disc life. According to the manufacturer, processes that are protected by KUB discs can operate at pressures that are up to 98% of the minimum burst pressure of the disc without risk of fatigue of the disc. — *Rembe, Inc., Charlotte, N.C.*
www.rembe.us

A vacuum-pump system for tabletop or mobile use

Turbolab high-vacuum pump systems (photo) are compact and pre-assembled, and are available with different configurations to cover a wide range of vacuum demands. The system's turbo pumps feature an oil-free hybrid bearing design. Turbolab systems are available in tabletop or mobile-cart versions, and each version can be cus-

Rembe

Oerlikon Leybold Vacuum

Cashco

Vindum Engineering

tomized with a variety of accessories, including purge-gas or venting valves, cooling units, heater bands and more. The system features dedicated ports for the connection of six different accessories and two gages. Monitored data are automatically stored to a data log file in the Turbolab system. Users can then view the log file with the Turbolab data-viewer software tool or via a Web-based data viewer. — *Oerlikon Leybold Vacuum GmbH, Cologne, Germany*
www.oerlikon.com/leyboldvacuum

This back-pressure regulator is available in five different sizes

Applications for the new Model BR back-pressure regulator (photo) include overpressure regulation of cryogenic liquids, sour gas, industrial gases and chemicals, as well as common industrial fluids like water, oil, steam and compressed air. Available in globe or angular porting configuration, the Model BR controls inlet pressures up to 200 psig in multiple spring ranges. The BR regulator is available in five sizes ranging from 3/8 to 2 in., and can handle materials from 20 to 400°F, with the appropriate combinations of body, spring chamber and trim materials. Trim designs include metal-seated or composition-seated with a metal or composition diaphragm. — *Cashco, Inc., Ellsworth, Kan.*
www.cashco.com

Use these metering pumps at pressures up to 12,000 psi

VP-Series metering pumps (photo) are designed for applications requiring continuous, pulse-free fluid flow at pressures up to 12,000 psi. VP Series pumps are controlled by either the company's proprietary VPWare software or by a customizable library of LabVIEW virtual instruments (VIs), both included with the pump. Either option gives the user complete control over pumping pressure and flowrate from a number of operating modes. Three models of VP-Series pumps are currently available, with the following maximum pressures and flowrates: 12,000 psi (30 mL/min); 6,000 psi (60 mL/min); and 3,000 psi (105 mL/min).

A 24,000-psi (15-mL/min) model will also be released in mid-2016, the company says. All models are available with either Hastelloy or stainless-steel wetted parts. — *Vindum Engineering, Inc., San Ramon, Calif.*
www.vindum.com

A leak-detection solution for helium and hydrogen

The ASI 35 modular leak-detection system is especially suited for use with tracer gases, such as helium and hydrogen, in integral and localizing test procedures, or a combination of both, with minimum signal background and crosstalk, providing for fast overall cycle times, reportedly as short as 1 s. The modular design of the ASI 35 minimizes space requirements and simplifies integration options — only two cables are needed to connect the vacuum and electronic modules. The ASI 35 features a low-maintenance turbo pump for high helium pumping speeds and dual independent filaments. The leak detector is designed for working conditions in ambient temperatures up to 45°C. — *Pfeiffer Vacuum, Nashua, N.H.*
www.pfeiffer-vacuum.com

This ribbon blender meets sanitary standards

Munson Machinery

The HD-3.5-7-S316 ribbon blender (photo) is constructed of 316 stainless steel to meet sanitary standards, and can blend up to 65 ft^3 of powders, pastes or slurries. The blender's two-to-one length-to-diameter ratio is said to distribute ingredients uniformly during loading, blending and discharge. It forces a split double-helical agitator through stationary material, producing homogeneous blends. Tight tolerances of 1.6 to 0.8 mm between ribbon blades and the vessel wall minimize residual product in the trough following discharge, reducing material waste and cleaning time. — *Munson Machinery Co., Inc., Utica, N.Y.*
www.munsonmachinery.com

These induction motors feature many frame and cooling options

The new TM21-G family of induction motors is designed for driving pumps, compressors, fans, conveyors and mine hoists. Standard features include frame sizes ranging from 315 to 900 mm, with maximum output power of 23,000 kW. Rated voltages range up to 11 kV. The maximum speed, operating from a variable frequency drive (VFD), is 3,600 rpm. Various cooling options are available, including fan cooling, air-to-air cooling and water-to-air cooling. Users can choose either anti-friction bearings or sleeve bearings. — *Toshiba Mitsubishi-Electric Industrial Systems Corp. (TMEIC), Roanoke, Va.*
www.tmeic.com

Mary Page Bailey

Organic Chemical Functional Groups

Department Editor: Scott Jenkins

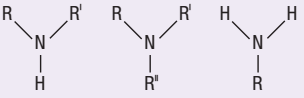
Alkyne R — C ≡ C — R'

Hydroxyl R — OH

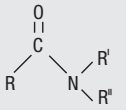
Aldehyde

Ketone

Amine



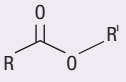
Amide



Carboxylic Acid

Ether

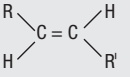
Ester



R and R' represent alkyl groups

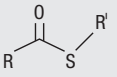
Sulfide

Alkene

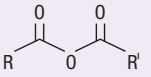


Nitrile R — C ≡ N

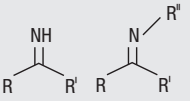
Thioester



Acid anhydride



Imine



Sulfone

Thiol R — SH

Acyl halide

X = Cl, F, Br, I

Chemical functional groups are critical determinants of the properties and reactivity of compounds. The following provides a review of the structures of common organic functional groups, along with some notes and examples.

Alkyne. Acetylene is used as a fuel for gas welding and a raw material for chemical manufacturing.

Hydroxyl. Alcohols and phenols contain this functional group, which is capable of forming hydrogen bonds.

Aldehyde. Formaldehyde and acetaldehyde are important industrial building blocks used in resins, wood adhesives and others.

Ketone. Acetone, cyclohexanone and methylethyl ketone are important ketones, used as solvents or in the manufacture of pharmaceuticals, polymers, fragrances and more.

Amine. Derivatives of ammonia, amines are important biologically (amino acids, neurotransmitters), as well as in industry. Aniline and ethanolamines are important in manufacturing dyes, rubber, pharmaceuticals, synthetic resins and more.

Carboxylic acid. Acetic acid, butyric acid and fatty acids are among the important carboxylic acids. Fatty acids are key components of many soaps and detergents.

Ether. Diethyl ether is used as both a laboratory and industrial solvent and reagent, as well as an engine starting fluid and in smokeless gunpowder.

Ester. Esters are used in polymer manufacturing, and are common in flavors and fragrances.

Sulfide. Sulfides have been used as presulfiding agents to prevent coke formation in ethylene production and in petroleum refining to presulfide hydrodesulfurization catalysts.

Alkene. Alkenes are building blocks for plastics (polyethylene and polypropylene), among many other uses.

Acid anhydride. Acetic anhydride is used to prepare acetate esters, while the cyclic molecule maleic anhydride, is widely used in industrial coatings.

Imine. Imines are used as ligands in organic chemistry

Sulfone. The sulfone sulfolane is used in the manufacturing process for BTX (benzene, toluene and xylenes).

Thiol. Methyl mercaptan is used as an odorant to allow the detection of natural gas by smell.

Thioester. Thioesters appear as intermediates in biochemical reactions. ■

Methanol Production from Natural Gas

By Intratec Solutions

Methanol (methyl alcohol) is an important chemical commonly used as a solvent, as a starting material in the production of chemicals and in the fuels sector. In recent years, technologies that have developed using methanol as the main raw material include methanol-to-gasoline (MTG), methanol-to-olefins (MTO) and methanol-to-propylene (MTP) processes.

The process

The following describes a process for producing methanol from natural gas that employs combined reforming for the generation of synthesis gas (syngas). Figure 1 presents a simplified flow diagram of the process, showing the main equipment. Companies offering combined reforming technologies similar to the one discussed here include: Air Liquide Global E&C Solutions; Toyo Engineering Corp.; KBR Inc.; Johnson Matthey and Haldor Topsoe A/S.

Syngas generation. Natural gas feedstock passes through a desulfurization step and is then fed to a saturator, where process water is supplied until gas saturation is achieved. The saturated natural gas is then sent to a pre-reformer for converting the larger hydrocarbons in the feed gas into a gas rich in methane and hydrogen. The pre-reformed gas is split into two streams: a portion is fed to the steam-reformer, with the balance being fed directly to the autothermal reformer (ATR).

In the steam reformer, methane reacts catalytically with steam, generating CO and H_2. In the ATR, methane is converted to CO and H_2 using oxygen as the reforming agent. The ATR outlet stream is then cooled and the condensed water is separated from the syngas.

Methanol synthesis. The syngas is compressed and mixed with recycle gas before feeding the methanol-synthesis reaction system. The methanol synthesis consists of reactions of CO and CO_2 with hydrogen to generate methanol. The reactor outlet gas is mainly comprised of methanol, water vapor, unconverted hydrogen, CO and CO_2. This stream is cooled, and methanol and water are separated from the gases by condensation. The separated gas is recycled with a small purge. The water-methanol condensate stream is sent to be purified.

Purification. The purification area is composed of three distillation columns. The topping column removes the dissolved gases from the crude methanol stream. In the pressurized methanol column, part of the methanol produced is obtained from the top of the column. The bottom of the column, still containing some methanol, is sent to the atmospheric column to recover the remaining methanol.

Methanol pathways

Currently, methanol is produced on an industrial scale primarily by catalytic conversion of syngas. The syngas is, in turn, most commonly produced from the natural gas reformation or by gasification of coal. The gasification process can also be used for the production of "green" methanol from biomass. Figure 2 shows different pathways for methanol production.

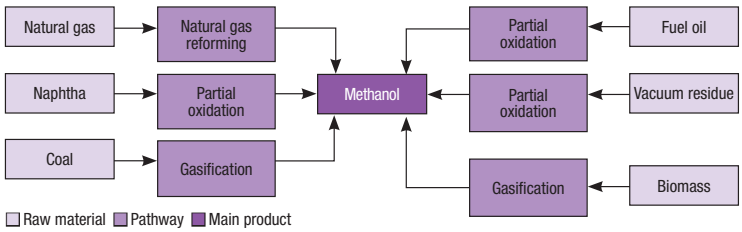


FIGURE 2. Several pathways are available for producing methanol

Economic performance

The total capital investment estimated to construct a plant with capacity to produce 1,700,000 metric tons per year of methanol in Q1 2014 in the U.S. is ~$1 billion. The capital investment includes fixed and working capital, and additional capital requirements. The production costs (costs associated with the plant operation, selling of products, administration, R&D activities and depreciation) are about $260/ton of methanol produced.

This column is based on "Economics of Methanol Production from Natural Gas," a report published by Intratec. It can be found at: www.intratec.us/products/methanol-production-processes. ■

Edited by Scott Jenkins

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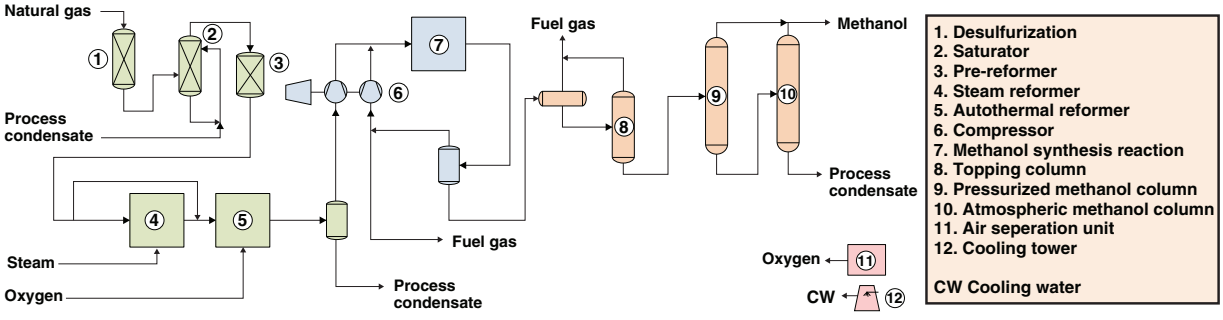


FIGURE 1. This flow diagram shows methanol production from natural gas via combined reforming

Harnessing Biotechnology: A Practical Guide

Biotechnology is increasingly proving its ability to address chemical industry challenges. An engineering-focused approach — bioengineering — is vital to successful industrial application

Steve Weiss
Genomatica

IN BRIEF

FIGURE 1. At Cargill's biorefinery in Blair, Neb., companies such as Corbion, Evonik and Natureworks produce bio-based products

For those undertaking overall process design and implementation for intermediate and specialty chemicals, the incorporation of biotechnology-based processes has become a viable option for the chemical process industries (CPI). Bioprocesses have the potential to deliver benefits in cost, quality and sustainability.

Many well-known chemicals are already produced biologically. For example, Cargill Inc. (Minneapolis, Minn.; www.cargill.com) produces lactic acid for polymer applications at petrochemical scale at its Blair, Neb. site (Figure 1) using a proprietary, low-pH, yeast-based fermentation process. DuPont Tate & Lyle Bioproducts Co. (Loudon, Tenn.; www.duponttateandlyle.com) produces 1,3-propanediol biologically, after DuPont determined that bio-based production would cost less than chemical routes to that product. BASF SE (Ludwigshafen, Germany; www.basf.com) produces vitamin B2 (riboflavin) biologically and has replaced its established chemical route. Lysine is another example of a large-volume chemical produced biologically. And 1,4-butanediol (BDO) is the next bio-based commercial process on the horizon: BASF and Novamont Sp.A. (Novara, Italy; www.novamont.com) have licensed technology from the author's company to produce BDO biologically.

This article is not intended as an introduction to biology, nor a recap of bioprocess advantages or case studies (see *Chem. Eng.*,

November, 2015, p. 40). Rather, the article is intended as a practical guide for how to think about, plan for, and integrate bioprocess technologies into chemical production facilities. To do this, the article highlights similarities and differences between bioprocess and conventional chemical process designs, equipment and operations, while strongly emphasizing cost economics and overall process analysis.

Principle 1: Whole-process design

A well-known idiom states: "begin with the end in mind." This suggestion — in the current context, designing a process with the whole system in mind — is appropriate.

The first part of our framework recognizes a key idea: chemical engineers had it right all along. Chemical engineers have decades of experience in designing and optimizing integrated, large-scale processes to convert raw materials into useful products. In its best application, considerable effort is invested upfront, in the form of conceptual designs, even before the associated experimental program is launched.

By contrast, many of the headlines associated with the rise of biotechnology-based processes have focused on specific technologies, tools and advances. Among the favorite topics are the tools for designing microorganisms (sometimes referred to informally as "bugs"). For the purposes of this article, the specific biology is not important — these engineered microorganisms can be thought of as fancy, biology-based "super-catalysts" that can perform multiple unit operations, such as all the steps needed to convert sugar into a desired target chemical with high specificity and minimal byproducts. While the progress has been impressive in using new biological tools to shorten the timelines to engineer an organism suitable for a proof of concept, the reality is that commercializing a bio-based technology is not just about the bug.

Instead of thinking about bio-based process design as a linear sequence (first, design the bug, then figure out the unit operations to best separate and purify its output, and then loop back to tune the design of the microorganism), a better approach is to "co-develop" and "co-optimize" the microorganism in conjunction with the overall process. Table 1 illustrates the differences between these two approaches — the "bug-first" approach is designated as "bio-centric" in the table, and the co-optimization approach is designated as "whole-process."

TABLE 1. BETTER PROCESS PERFORMANCE THROUGH WHOLE-PROCESS THINKING

"Bio-centric" approach	"Whole-process" approach
Focus: Maximize microorganism performance (for example, titer, rate and yield)	*Focus*: Design microorganism and overall process to minimize total production cost, meet all specifications and maximize operational robustness
Priority: Laboratory-scale strain and fermentation development is prioritized, supported by computational tools and iterative strain design, testing and metric optimization	*Priority:* Choose microorganisms and metabolic pathways that are compatible with the lowest-cost operating conditions (for example, pH, temperature, aerobic versus anaerobic, co-product value). Design the microorganism for the process, not the other way around
Process design: Process is designed subsequently to fit the needs, capabilities and limitations of the microorganism	*Process design:* Pay close attention to managing process impurities (raw material residuals, metabolic byproducts, chemical reaction products) that could otherwise increase capital and operating costs, or compromise product quality
Process performance: Performance in the laboratory may not be realized at large scale due to overlooked, scale-dependent parameters. Or, high performance at large scale may require special (expensive) operating conditions, be more sensitive to process upsets (less robust), more subject to contamination by foreign microbes (plant shutdown), or incur higher downstream processing costs	*Process performance:* Develop the microorganism and process at laboratory scale under anticipated large-scale conditions (time and temperature profiles, mixing times, pressures, recycles). Characterize key process sensitivities. Demonstrate the whole process at an appropriate scale to document its performance with engineering data. Use those data as the basis of detailed plant design
Downstream processing: Downstream processing is not addressed until the late stages of development (when the microorganism and fermentation are nearly finished). It is the responsibility of downstream processing to identify and solve any problems that have arisen upstream. This invariably adds cost.	*Downstream processing:* Microorganism is designed for the process, to enable least expensive operating conditions (includes pH, aerobic versus anaerobic, fermentation time and so on)
Plant: Large-scale plant is designed and built to accommodate the laboratory-scale process	*Plant:* The whole-process approach translates directly to design of large-scale plant, minimizing changes and added costs

We refer to this whole-process discipline as *bioengineering*. This approach better captures the intimate intertwining of, and co-optimization across, multiple disciplines.

While everyone can surely appreciate — and even marvel at — the continued advances in specific parts of the biology toolkit, the best practice is to take a whole-process view when exploring how to harness bio-based processes as a component of a plant construction project. Product customers may also marvel at the science underlying a particular microorganism, but ultimately, they are really looking for ways to lower costs, raise product quality and improve the sustainability profile.

Principle 2: Extend TEA

The second principle in evaluating and deploying biotechnology is to apply one of the most favored tools from conventional process technology: techno-economic analysis (TEA).

TABLE 2. CAPITAL COSTS PER TON OF PRODUCT FOR CONVENTIONAL AND BIO-BASED PLANTS (EXAMPLES)

	Conventional	Bio-based	Comparison
100,000-ton/yr plant	$300 million total $3,000 per ton	$230 million total $2,300 per ton	Bio is 23% lower
50,000-ton/yr plant	$200 million total $4,000 per ton	$140 million total $2,800 per ton	Bio is 30% lower

Source: Genomatica estimates, based on industry analyst data, company data and discussions with chemical producers. Assumes scaling exponent of 0.6 for conventional and 0.7 for bio-based at these ranges of capacity

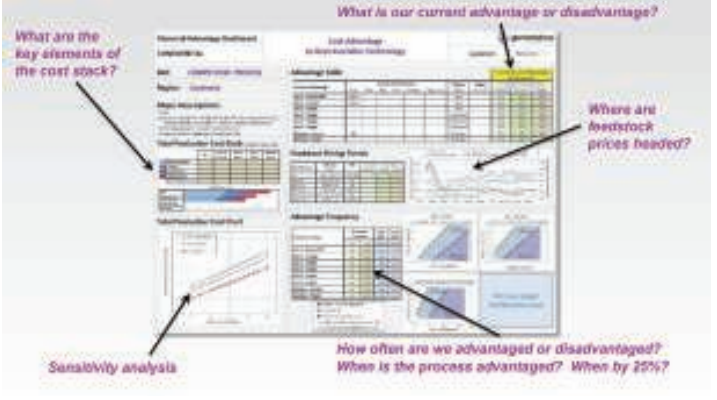
Many readers are likely already familiar with TEA, and may use it to better understand the overall economics of potential process designs for conventional chemistry-based processing. The idea is to apply the same concepts of TEA to bio-based processes (see sidebar, p. 41). Some of the individual line items of the TEA will be different, but the overall goal remains the same — to generate an all-inclusive picture of the total capital investment and production costs for a potential process.

An important recommendation at this point is to create a management dashboard to facilitate internal discussion and decisions (Figure 2). If biotechnology is a new area for your organization, then this kind of dashboard will help your team become more comfortable with how process economics change under varying conditions (for example, historical data, forecasts, competitive processes, alternative feedstocks and geography).

Similarly, you can expect questions about the competitiveness of bio-based processes, especially given the current low prices of crude petroleum in 2016. A helpful way to approach this is by creating indifference curves (essentially, sensitivity analyses), which provide an unbiased perspective on overall process economics. For example, as shown in Figure 3, the x-axis corresponds to the feedstock price for a conventional process and the y-axis is the feedstock price for a bio-based process. The first line to draw is where total production costs are equal for the two competing process technologies. The region on one side of that line shows all the feedstock price combinations where one process technology is lower cost; and the other side of that line shows the price combinations where the other process is favored. Next, map historical data points, and see which process technology would have delivered lower costs given actual feedstock prices over time (as shown by the Xs and circles in Figure 3). Lastly, draw additional lines to highlight the relative feedstock pricing when one process delivers, for example, a 25% cost advantage. By doing so, you can get a feel for how processes compare over time, even when using different feedstocks.

Interestingly, some bio-based processes may offer lower total process costs even with the current low prices of fossil-based feedstocks. And many analysts believe that petroleum-based feedstocks will eventually return to higher, more traditional prices, which may provide a truer point of comparison for when a new plant begins operation.

FIGURE 2. Management dashboards, such as the one shown here, can facilitate internal discussions of techno-economic analyses



Principle 3: Rethink economics

Economics is not just about total production cost (or even the economic cost of goods sold, which includes consideration for a return on capital employed (ROCE)). Bio-based processes can bring additional potential economic advantages, including deployment flexibility, greater price stability and lower safety and operations risks.

Let's start by looking at the forces acting on capital expenditures. First, the capital cost per ton may be significantly lower (sometimes 20–40%) for bio-based process technologies than for conventional chemical processes using fossil feedstocks — especially for mid-sized plants (Table 2). This is because a single bio-based unit operation (fermentation) frequently replaces multiple conventional unit operations. Additionally, capital equipment for that process may be less expensive (for example, with bio-based operations running at near-ambient temperature and pressure and near-neutral pH, versus the more challenging conditions often required in a conventional chemical process). Generally, only the largest conventional plants will not be disadvantaged in capital cost per ton. Second, the plant-scaling exponent is higher for bio-based processes, and this *increases* the cost-per-ton advantage for bio-based processes as

TECHNO-ECONOMIC ANALYSIS FOR BIO-BASED PROCESSES: NEW EXAMPLES

The use of techno-economic analysis (TEA) is all about understanding tradeoffs — the interplay between process design decisions and both capital and operating expenses.

TEA can be used when implementing a bio-based process in the same way it would be used for a conventional process. In the bio-based process, however, some new types of unit operations and equipment are in play, and they have different trade-offs compared to conventional processes. TEA can be used the same way, just with some substitutions.

As an example, consider fermentation. At first blush, it seems to be just a big tank, but in fact, process design — and tank design — can have a significant impact on capital and operating costs. Is it better to use a smaller number of large fermentation tanks (for instance, 1,000 m^3) or a larger number of smaller tanks (100 m^3)?

Other questions also must be answered, including whether the process will use aerobic or anaerobic microorganisms; whether a bubble column or stirred-tank reactor should be used; whether to control temperature with a cooling jacket, internal coil or external loop; and whether the process will be run as a batch or continuous process.

For separation and purification, considerations include feedstock quality (for example, more impurities at the start likely mean more effort and cost later); handling of solids both upstream (for example, biomass pretreatment and sucrose handling) and downstream (crystallization and drying); and the properties of the target chemical (such as solubility, volatility, permeability, target purity).

The net effect of these factors can be significant. For example, designing a bio-based process for lysine will tend to have higher capital costs per ton of annual production capacity (about $3,000 per annual ton), as compared to a process design for ethanol (approximately $600). Successful lysine processes have been aerobic; aseptic; use jacketed fermenters with chilled water; use semi-refined feedstocks; and need extensive downstream separations. Ethanol processes work well with large fermenters; are anaerobic and sanitary, and use external cooling loops and unrefined feedstocks. Ethanol processes also have easier separations due to its higher volatility.

These factors can also shift the balance of capital and operating expenses, with one type of process design being better at larger scale and another at smaller scale.

smaller plants are built.

For decades, the chemical industry has moved in the direction of building ever-larger plants, in part to increase efficiency by reducing capital expenditure per ton. Now, with the capital advantages of bio-based processes, the industry can gain the option to go the other way — to economically deploy smaller, "right-sized" plants. This can allow entry into a local or regional market, and can allow capacity expansion without the large outlays needed for a mega-sized plant or the risk of disrupting the supply-and-demand market balance. It can also enable users of chemicals to backward-integrate and produce their own supplies, as Novamont is doing with bio-based 1,4-butanediol in Italy, with a planned start-up in the second half of 2016.

Readers should also consider the potential for better overall economic performance of a plant because of the greater sustainability of the chemical being produced and sold there. While this article's discussion so far has treated plant output as a direct substitute (that is, as a commodity), a bio-based plant may deliver a product with a smaller environmental footprint — and may be seen by customers as a more sustainable and desirable option. This is not the same as assuming a "green premium" based solely on sale price. Selling a more sustainable version of the same product may enable a supplier to gain longer-term customer commitments, or reduce the discounts it needs to offer to customers (especially during times of weak demand) — both of which improve the true economic performance, offering a more comprehensive view than a TEA.

Additional considerations in the broader economic picture are safety and operations-related risks. Accidents happen. And accidents at conventional plants, operating at high temperature and pressures and sometimes with toxic chemicals, can be very costly. By contrast, the less severe conditions of a bio-based process, combined with the aqueous-based environment of fermentations, reduce process-safety risk.

Lastly, the chemical industry has de-

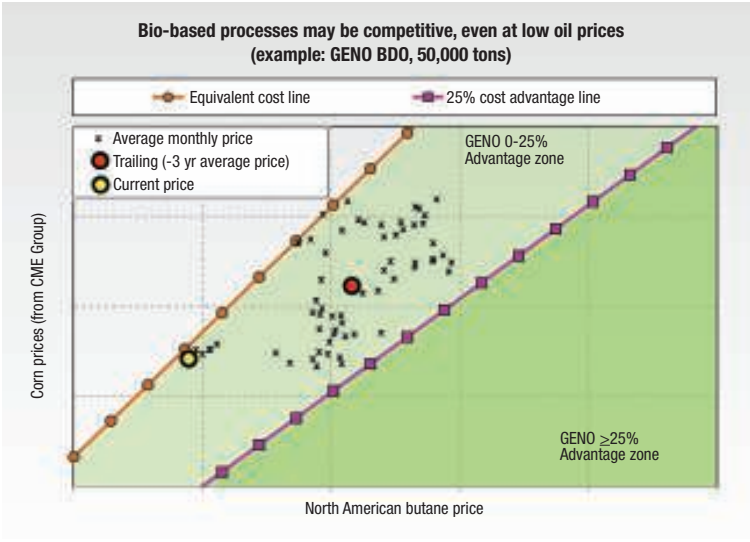


FIGURE 3. Indifference curves can help compare process economics of two alternative processing pathways

veloped strategies to manage many economic risks, including those tied to feedstock costs. Increasingly, similar tools are available to support bio-based projects. For example, Cargill, the global agricultural products and services firm, has among its core competencies the ability to manage the pricing and supply risks tied to agricultural commodities — which may be used as feedstock for bio-based production plants. In addition, Cargill is now offering a range of production-support services to companies interested in specific bio-based process technologies, including fully outsourced production, services and feedstock supplies.

Principle 4: Bioprocessing is different

While bioprocess engineering and conventional process engineering are disciplines that share a similar overall approach, there are important differences in the specifics of the two, as well as some specialized skills associated with bioprocessing. The following items represent some examples.

Downstream processing is different. Chemicals made from fossil feedstocks have characteristic impurities, while those made biologically have different impurity profiles, even if both types of process technologies offer end products at the same purity level. For example, the feedstock for bio-based processes is often carbohydrates. These can lead to product-quality issues, such as color and odor, if not addressed during process design. The bioprocess engineer must be familiar with carbohydrate chemistry and nitrogen (protein, amino acids) chemistry, as well as methods for separating color and odor-causing compounds. Similarly, separating the desired chemical product from the fermentation broth may require different techniques and equipment. Fermentation-based processes operate in an aqueous environment (required for microbial life to thrive). Effective handling and purification of aqueous streams often dictates specialized unit operations. Key concerns include energy-efficient techniques to remove water and the ability to recycle and reuse water.

The tools to minimize byproducts are different. Removing byproducts is expensive, both in capital and operating costs. Bioengineering techniques generally allow the elimination of many byproducts from the outset, by designing a microorganism so that the byproducts are not produced in the first place. For example, initial strains of bacteria engineered by Genomatica to produce 1,4-butanediol also formed nitrogen-containing byproducts, such as 2-pyrrolidone. Strain modifications reduced this significantly, thereby reducing downstream processing costs. This ability to produce a targeted chemical with high selectivity can be a strong advantage.

Managing for variations in feedstock is different. Making a plant or process that is robust under varying inputs is a fundamental task for process engineers that impacts both capital and operating costs. The techniques for managing variations in feedstocks for bio-based processes are different than for conventional processes, and may include feedstock testing (to determine attributes), collaboration with feedstock suppliers to optimize consistency versus cost, rethinking the design of your microorganism to efficiently handle greater variation in feedstock properties, and adjusting fermentation or other operating parameters.

Requirements for sterility are different. Contamination is a concern in any production plant, but the manner in which it is realized for a bio-based process, and the rigor with which it must be maintained, are different. In particular, it is most often necessary to design, build, and operate a bio-based process to exclude viable foreign microbes. This is particularly demanding and critical in the fermenters and associated systems, and, depending on the product, can extend into downstream processing as well. The penalty for cutting corners on sterility can be severe.

Managing for the weather is different. For example, large-scale fermentations can be sensitive to the effect of outside temperatures on cooling-tower capacity. Insufficient cooling capacity can ruin a fermentation batch due to temperature run-up, with consequences that can extend into downstream processing. This risk can be addressed through operating procedures that adjust process parameters to slow down the fermentation rate to maintain temperature control of the fermentation process. Fermentation plants are often constructed with minimal enclosure and exposed piping. Given their lower operating temperatures and aqueous streams, it may be necessary to account for the possibility of freezing.

So what is the overall lesson here? Take advantage of people and firms that have bioprocess expertise as an integral part of your project planning and implementation. Missing this can be (and has been) a critical point of failure, just like trying to build your first-ever plant in a new part of the world without local

knowledge and resources. Coupled with Principle 1, this puts a premium on collaborating with partners that have proven experience in biotechnology, in bioengineering, and in taking a whole-process perspective.

The good news is that despite all these differences, large-scale commercial fermentation-based processes have been running for decades to make products like organic acids and amino acids. Recent advances in microorganism engineering have simply expanded the opportunities for employing bioengineering to develop cost-competitive, robust bioprocesses for a greater number of products and for a wider range of product types.

Principle 5: Evaluate services

If you have never bought a motorcycle before, it is important to learn the most important questions to ask and what tires to kick.

To successfully harness biotechnology in your projects, here are some key considerations in evaluating potential technology or project partners.

Design processes to operate at your targeted commercial scale. Technology should be demonstrated under large-scale conditions and piloted at a scale and to an extent necessary to mitigate scale-up risks. The best practice is to prioritize those technologies and partners that have "been there and done that" — they know what the end result should look like.

Invest in comprehensive integrated solutions. Do not take a piecemeal approach, where microorganism development, process development, TEA and large-scale plant design are disconnected activities.

Overprepare for technology transfer and take nothing for granted. It is easier to reduce resources later because technology transfer has gone smoothly, than to add resources to "fight fires." Prospective partners may offer validation of their technologies based on a plant that they have built, and now own and operate. Look for those that have successfully transferred their technology — ideally to multiple locations around the world — and possess documented, systematic approaches for doing so. If finding such a situation is difficult, look harder and persevere; they do exist.

Closing thoughts

Biotechnology brings increased options for many chemical-production businesses and offers more tools to harness where appropriate. There is a fast-expanding body of knowledge, experience, and best practices, from which all can benefit.

Our trade is tasked with planning for projects that start up three or more years from now. That means that now is the right time to learn how and where to integrate bioengineering and bring it into active consideration for your upcoming projects. ■

Edited by Scott Jenkins

Author

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Synthetic Biology for Chemical Production

Rapidly expanding computational power and decreasing costs for DNA sequencing and synthesis have made synthetic biology tools more accessible to chemical makers

Alexandre Zanghellini
Arzeda Corp.

IN BRIEF

Not long ago, the late former Apple CEO Steve Jobs said, "I think the biggest innovations of the 21st century will be at the intersection of biology and technology. A new era is beginning." Recent developments in the field of synthetic biology already seem to be validating his prophecy. The U.K.'s Royal Society (London; www.royalsociety.org) describes synthetic biology as the design and construction of novel artificial biological pathways, organisms or devices, or the redesign of existing natural biological systems.

FIGURE 1. Synthetic biology tools could help the CPI sustainably produce many chemicals for which natural pathways do not already exist

With his statement, Jobs was probably reflecting, in his later days, on the impact of this convergence between technology and biology specifically on human health. But other domains of human activity are poised to be equally impacted by synthetic biology (Figure 1). This includes our ability to sustainably produce the molecules that make up our chemicals, materials and drugs. DNA is commonly viewed as the "code," or software, of life. Now, an equally important view is the emerging ability of computer software to enable us to engineer living systems with unprecedented precision and speed.

Expansion of fermentation

The future of chemicals lies in fermentation, but it has not yet been fully realized. It has long been hypothesized that fermentation could ultimately replace conventional synthetic chemistry for the production of chemicals. After all, fermentation hosts, such as yeast, are actually miniature cell factories, able to catalyze numerous complex chemical reactions in a very small volume. Advantages of using such cell factories for industrial processes are many. Complex chemistry can be catalyzed under mild, low-energy conditions, contrary to most industrial chemical processes. Further, whereas conventional chemical processes usually start from nonrenewable resources (petroleum, gas or coal), fermentation processes typically convert plant residues (biomass) or other renewable resources into ultimately the same product, making it sustainable.

Perhaps even more importantly for the chemical process industries (CPI), fermentation can dramatically reduce the number of process steps, as well as operational costs and capital requirements, for a manufacturing plant. Most industrial chemical processes start from relatively simple petroleum-based chemical building blocks (hydrocarbons with a limited number of functional groups) and catalytically convert them into more complex fine and specialty chemicals. This typically requires multiple steps, each involving catalysis, extraction, purification and recycling, resulting in complex and expensive plants. The rapid

increase in engineering complexity to produce more complex molecules at large scale is one of the reasons for concepts such as BASF's (Ludwigshafen, Germany; www.basf.com) *Verbund* philosophy, which emphasizes the importance of capital efficiency and the reduction of waste, byproducts and costs.

By contrast, the costs for fermentative or biocatalytic processes are theoretically near constant with respect to the complexity of the molecule. If a cell factory is available to convert inputs into a complex chemical by embedding a set of highly efficient biocatalysts, the production process may only consist of two steps: fermentation and downstream processing. When considering a specific feedstock input (typically dextrose) and well-characterized industrial host, final processes at scale are therefore very similar.

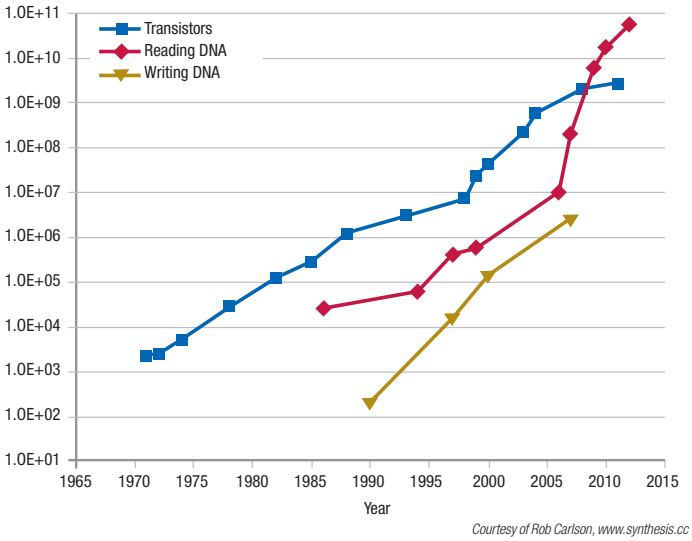
Breaking fermentation limits

Despite significant research and development investment over the last two decades by multinational chemical companies, such as DuPont (Wilmington, Del.; www.dupont.com), Dow (Midland, Mich.; www.dow.com) and BASF, and significant venture capital investments in startup technology companies, the value of bio-based chemicals produced is still a small fraction (around $54 billion) of the $1.4-trillion global chemical industry. Why is that the case, despite the advantages of fermentation? Although long timelines, complex value chains and several other factors may partly explain the relatively slow pace of adoption of new fermentative technologies by the chemical industry, one of the primary reasons lies in the technological limits to the state-of-the-art in biological engineering; namely the field of synthetic biology.

For the most part, microbial strain-engineering techniques are limited by serendipity and are nowhere close to the level of robustness found in chemical engineering. Until the recent advent of disruptive technologies discussed later in this article, fermentation technology has been limited to manufacturing molecules that are naturally produced by microorganisms and for which biosynthetic pathways are well understood. This includes ethanol, citric acid and monosodium glutamate (MSG).

Natural microbial strains simply are not capable of producing most of the chemicals in the $1.4 trillion global market. In some cases, screening of natural diversity can identify organisms that produce a desired industrial chemical at very low concentration (or, titer). Even when that is the case, optimizing and scaling up an organism whose genotype and physiology is not very well understood is a risky and arduous task.

As a community, biochemical engineers have developed effective process technologies for a very limited number of so-called industrial strains, among them *Escherichia coli* and *Saccharomyces cerevisae* (baker's yeast). Even with such strains, optimization to reach industrial performance in terms of titer, productivity and yield is also a long and risky process. A well-publicized example is that of leading industrial biotechnology company Amyris Inc. (Emeryville, Calif. www.amyris.com): it



Courtesy of Rob Carlson, www.synthesis.cc

FIGURE 2. The number of DNA base pairs sequenced and synthesized has expanded in parallel with the number of transistors per computer chip

took around five years and several hundred million dollars in investment for Amyris to optimize and scale-up its yeast strain for the production of the molecule farnesene. Similarly, in a fantastic engineering feat, Genomatica was able to start with an *E. coli* strain producing only detectable titer of the chemical 1,4-butanediol (BDO) and through several years of optimization, obtained an industrial strain reaching titers of greater than 100 g/L. The exact price tag here is not public, but is most likely in the same range as that of the Amyris case. Other similar examples include DuPont's 1,3-propanediol (1,3-PDO) and Evolva's strain development for the production of vanillin and stevia.

To deliver on the vision of sustainable, bio-based chemicals, these limitations ought to be urgently addressed. As long as it takes five years and over $100 million of R&D expenses to develop a new industrial strain, bio-based chemicals are doomed to remain at the margins of the industrial chemical world.

Moore's law and Carlson's curve

The current state of affairs is being disrupted by several concurrent trends. In each of them, technology and exponential growth play a critical role. Computational power has expanded according to Moore's law, which states that the number of transistors in computer microprocessors doubles every 18 months. The enormous amount of computational power now available in the "cloud" has allowed many previously intractable biological-design problems to finally be tackled.

Somewhat less known is the exponential decrease in the cost of DNA sequencing and DNA synthesis, a development that has been dubbed Carlson's curve (Figure 2). Over the last two decades, the cost of DNA sequencing has decreased to a point where sequencing the genome of a microorganism can be achieved routinely for only a couple thousand dollars (that cost is poised to decrease further in next several years, to the range of a couple of hundred dollars per microbial genome). What this means is that the volume of sequence and genomic data deposited in public databases has also increased exponentially, making it possible today to use "big data" tools and machine-learning techniques to help guide the design of fermentation strains for the production of bio-based chemicals.

The complement of DNA sequencing is DNA synthesis, where a sequence of DNA is specified in the computer and the corresponding DNA molecule is synthesized chemically. Recent technological developments have dramatically increased capacity and availability, while decreasing the cost of DNA synthesis.

Next-generation DNA synthesis is leveraging microarray technologies, where short stretches of DNA called oligonucleotides are synthetized at very high density on a chip and further assembled into the final full-length synthetic gene. Agilent Technologies (Santa Clara, Calif.; www.agilent.com), Gen9 Inc. (Cambridge, Mass.; www.gen9bio.com) and Twist Bioscience (San Francisco, Calif.; www.twistbioscience.com) are some of the leading companies that have implemented this technology at scale. Collectively, these companies are now serving a global market of around $300 million in 2016, a total that is predicted to grow exponentially.

Conversely, the cost per base of DNA synthesized has now dropped to $0.10 per DNA base pair, which translates to around $100 per synthesized gene. Mirroring what has happened in the world of semiconductors and computer processors, the technological developments in DNA sequencing and synthesis are signs of impending commoditization: biotechnology is entering the era of "cheap DNA." This new era already has had, and will continue to have, highly positive impacts on microbial strain design, strain construction and the manufacturing of bio-based chemicals.

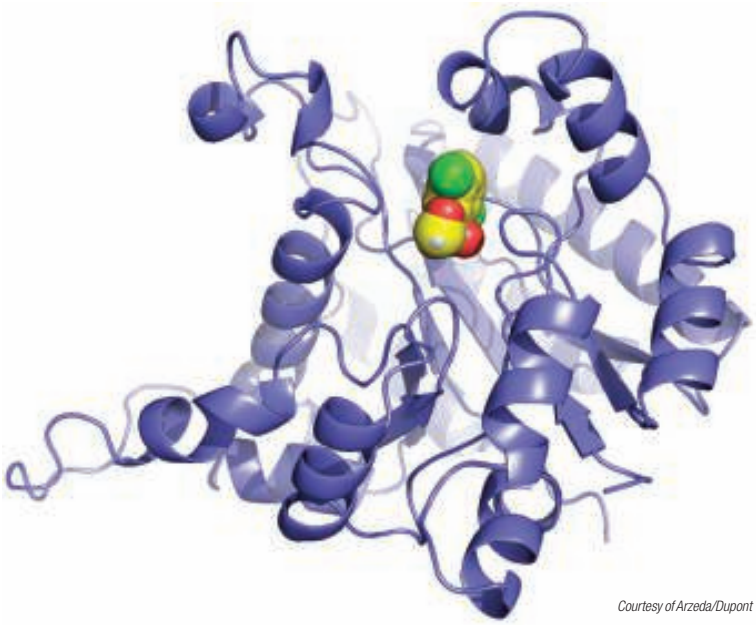
The emergence of dedicated 'fabs'

The ability to synthesize DNA on a massive scale is transforming how we optimize fermentation strains for industrial purposes. Over the last decade, significant public and private investments have been made in the infrastructure and technology to construct

and fabricate optimized strains (such facilities are being referred to, in casual parlance, as "fabs"). One of the pioneers in this area is Amyris. Since 2003, the company has been building an automated pipeline for strain construction. Given a particular design (that addresses questions such as which knock-out mutations to include, what variant of an existing gene is necessary, or which regulatory elements need to be engineered to improve production of a target molecule), Amyris' pipeline can design the required DNA sequence, perform DNA synthesis, and carry out high-throughput strain modifications by using a mix of bioinformatics tools. The resulting synthesized DNA is inserted into cellular hosts for testing and further development. This pipeline is reported to have reached the capability of building several thousand strains monthly, and capacity is ramping up, with a recent investment in Amyris' fab from DARPA's (U.S. Defense Advanced Research Projects Agency; Arlington, Va.; www.darpa.mil) Living Foundries program. This platform for strain construction and optimization is now accessible to other industrial partners through Amyris' platform program.

Newer entrants have also developed fabs that are very similar in principle to Amyris's pioneering approach, although the details of their implementation differ. Ginkgo Bioworks (Boston, Mass.; www.ginkgobioworks.com) is investing massively into the construction of standardized metabolic parts (known biocatalysts that are well characterized) and automation of construction of strains that reuse these naturally occurring parts to produce flavor and fragrances that are normally sourced industrially from plants.

Zymergen Inc. (Emeryville, Calif.; www.zymergen.com), founded by a team of veterans from Amyris, is also building a fully automated fabrication platform that leverages recent advances in gene editing to be able to not only optimize traditional industrial fermentation strains (*E. coli* and baker's yeast), but also less well-characterized organisms. Finally, in the public sector, the Broad Institute (Cambridge, Mass.; www.broadinstitute.org) and MIT (Cambridge, Mass.; www.mit.edu) have also been awarded a DARPA Living Foundries award to develop a public strain fab focused on building complex naturally occurring pathways into heterologous strains.



Courtesy of Arzeda/Dupont

FIGURE 3. Computationally designed enzymes, like the one represented by this structure (an enzyme to catalyze the decarboxylation of the herbicide dicamba), offer a peek into the future of designer cell factories for new chemicals

Although it is premature to talk about commoditization for strain construction, the proliferation of such fabs that follow a service-and-partnering business model suggests that this strain-construction capacity will be increasingly accessible to companies seeking to develop fermentation-based processes for chemicals, agrichemicals and pharmaceuticals.

Perhaps in a slightly longer timeframe, one can even imagine a situation where strain construction will be done completely in the cloud. This is the model put forward by companies such as Transcriptic (Menlo Park, Calif.; www.transcriptic.com). The company is pushing its "cloud wetware" concept: strain designers specify the experiments that they want to see performed, using a computer description of protocols that gets executed by robots at Transcriptic. Only data and results are transmitted back for analysis and further iteration.

Designer biocatalysts

In the computing industry, Moore's law effectively resulted in a shift in value creation from hardware to software. That is, the value-add became concentrated in designing the software that runs on the hardware, as opposed to building the hardware itself. Cheap DNA, cheap central processing unit (CPU) cycles and the availability of

automated general-purpose strain-construction fabs are all converging. From a business perspective, this means that value creation will be shifting from making natural organisms more efficient to designing synthetic biocatalysts and organisms capable of producing the most valuable chemicals, even if the natural starting organism does not "know" how to make them (Figure 3).

Technologies that leverage large-scale cloud computing and big data to design novel biocatalysts and fermentation strains in order to produce chemicals have started to appear in recent years. Developing a designer cell-factory that produces a new chemical generally entails being able to rationally engineer a cell at multiple levels. At the lowest level, the production of a target small-molecule generally requires the design of new enzymes that catalyze — efficiently and specifically — new chemical reactions. Each natural enzyme is encoded by a gene sequence that specifies the catalytic active site within the enzyme macromolecule. The need to create enzymes for new chemical reactions is usually referred to as the "enzyme design" problem.

Natural enzymes are extremely efficient at catalyzing very difficult chemical reactions under mild conditions that differ drastically from what conventional chemical catalysis often requires. Textbook enzyme examples, such as orotidine decarboxylases, show catalytic rate enhancements at pH 7.0 and 30°C of 1×10^{18} times the non-catalyzed reactions. However, predicting the genetic sequence that will lead to an enzyme capable of performing a specific reaction that is not catalyzed in nature has been one of the most recalcitrant problems in biochemistry for decades, and is largely responsible for some of the failures in bio-based chemicals.

Pioneering academic work by Frances Arnold at the California Institute of Technology (Caltech; Pasadena; www.caltech.edu) and commercial work by Willem "Pim" Stemmer formalized the technique of "directed evolution." The concept involves starting with an enzyme that catalyzes the desired chemical reaction, and painstakingly reproducing nature's evolutionary mechanism to accumulate mutations until a DNA sequence results that encodes for an optimized enzyme. This method still requires, however, screening vast amount of natural genes to find starting points having the initial desired activity.

Another concept, known as computational enzyme design, has been pioneered in the academic laboratories of David Baker at the University of Washington (Seattle; www.uw.edu) and Steve Mayo at Caltech, and is being commercialized by the author's company Arzeda Corp. (Seattle, Wash.; www.arzeda.com). Computational protein design bridges the gaps in directed evolution and makes it possible to design new enzymatic activities. Computational enzyme design uses vast amounts

of computational power to screen amino-acid sequences and select the ones that will provide the desired catalytic activity. Cloud computing can enable the use of thousands of decentralized CPUs for enzyme design calculations. The DNA encoding the designed libraries of sequences is then synthesized and incorporated into cellular hosts for testing and further improvement.

New pathways

Biosynthesis of a chemical of industrial interest usually requires an "assembly line" of multiple enzymes inside a fermentation strain, each catalyzing a distinct chemical reaction, but all collectively converting a starting molecule (feedstock) into the desired target chemical. In nature, these assembly lines are called metabolic pathways, and they are the result of hundreds of millions of years of evolution. To date, nearly all the bio-based chemicals manufactured by fermentation are actually made by these natural metabolic pathways, and the role of strain optimization is to fine-tune the balance between different metabolic pathways in the host strain.

Synthetic chemistry started to have an industrial impact when, toward the end of the 19th century, its techniques became efficient and robust enough to be able to design synthetic routes for new chemicals. Similarly, long-term value creation in synthetic biology will critically depend on our ability to integrate the design of new pathways, new enzymes, and downstream process development to produce the chemicals with the highest value to the industry.

Once again, the combination of cheap DNA and cheap CPU power has led to the development of such tools. Software that was pioneered in chemistry by the work of Nobel-laureate E.J. Corey for the automatic design of retro-synthetic pathways has found a direct analog in biochemistry. Given a desired molecule target, the software computationally surveys all possible enzymatic paths including natural as well as possible designed enzymes that lead from a starting metabolite to the target. DNA sequences for these pathways are then printed and strains implementing each of these pathways constructed, tested for target production and further optimized as necessary. Along with Arzeda, companies such as SilicoLife (Braga, Portugal; www.silicolife.com), 20^{n} Labs Inc. (Berkeley, Calif.; www.20n.com) and Abolis Biotechnologies (Evry, France; www.abolis.fr) are operating in this field.

The advent of such high-throughput design tools are opening entirely new avenues for bio-based chemicals and are poised to transform the chemicals, agricultural-chemical and pharmaceutical industries. Industrial R&D programs have been initiated to produce, by fermentation, 1,3-butadiene, a $23 billion per year chemical building block not known to be produced by any organism. Multiple industrial consortia, such as Braskem/Genomatica, INVISTA/Lanzatech/Arzeda and GlobalBioenergies/Synthos are competing here. Similar development efforts are underway for such chemicals as 1,4-butanediol (Genomatica/BASF and Bio-Amber/Mitsui), as well as for adipic acid.

If biology is indeed becoming more and more like technology, we can hope for a better future made of chemicals that are produced sustainably with a neutral or even negative carbon footprint, and improve performance in applications compared to products accessible via petroleum-based processes. ■

Edited by Scott Jenkins

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Alexandre Zanghellini is a co-founder of Arzeda (2715 West Fort Street, Seattle, WA 98199; Phone: 206-402-6506; Email: alexandre.zanghellini@arzeda.com) and serves as its CEO. Along with Arzeda's management team, he is responsible for day-to-day operations and also leads Arzeda's product and technology development. Zanghellini is one of the inventors of Arzeda's synthetic biology platform for novel enzyme and metabolic pathway design and is a keen believer in the power of biotechnology to solve some of our biggest societal challenges. Before founding Arzeda, Zanghellini held positions in research and development both in academia and industry. Zanghellini is the author of eight peer-reviewed publications, including articles in *Science* and *Nature*, and is an inventor on 16 issued patents and patent applications. He holds a Ph.D. from the University of Washington and a M.Sc.Eng. from ENSTA/ParisTech in Paris, France.

Characterize Bulk Solids to Ensure Smooth Flow

To minimize problems associated with handling all types of bulk solids, engineers must adopt a systematic approach to characterizing the flow and mechanical properties of the materials under a variety of operating conditions

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IN BRIEF

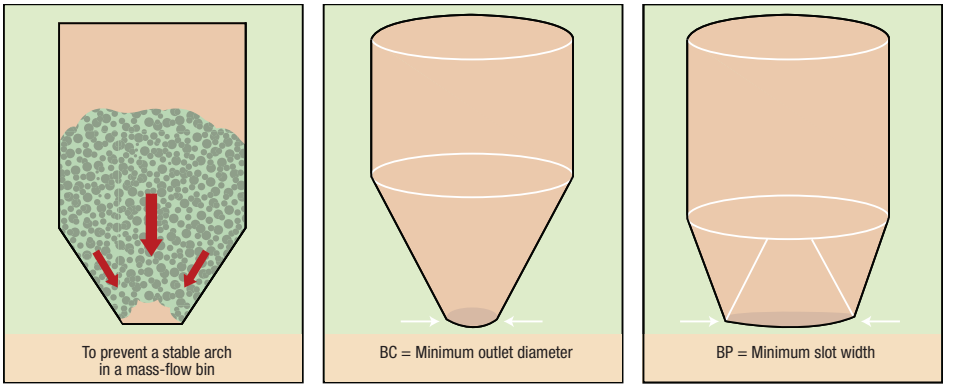

FIGURE 1. The size of the discharge outlet is a critical element in preventing the formation of an arch in a mass-flow bin

Bins, hoppers, feeders, and conveyors handle bulk solids in virtually every industry — from chemicals and pharmaceuticals to power generation and mining. During operation, the behavior of bulk solids in such equipment is not always reliable.

Non-uniform flow can be expensive in terms of inefficient processes, wasted product, and operational nightmares. Predictable flow may be impeded by the formation of an arch or rathole, or fine powders may flood erratically or even uncontrollably.

Armed with information about the flow and granular properties of the material itself, engineers can optimize the selection of storage, feeding, processing and conveying equipment. These same properties can be used to retrofit existing facilities to correct flow problems.

For many engineers, a material's name, such as polyethylene powder or sodium tripolyphosphate, connotes some useful information about its handling characteristics. While this may be true in a general sense, it is not a reliable tool. Unfortunately, major differences in flowability occur between different grades and types of materials with the same name.

Four poor design-basis attributes

The four attributes mentioned below are often relied on to predict the behavior of bulk solids. However, they rarely provide engineers with direct assistance during the design or specification of a bin, hopper, feeder or conveyor.

Angle of repose. Determining the angle of repose is easy: simply form a pile of material and measure its slope. Knowing what to do with the data is the difficult part. For most materials, the angle of repose varies significantly depending on how the pile was formed. Furthermore, the mechanics of pile formation bear little resemblance to either the formation of an arch or rathole in a bin or hopper, or to the other key parameters needed when designing a material-handling system. In general, a material's angle of repose is not an accurate measure of its flowability. Its main utility is in determining the height and volume of a pile.

Particle-size distribution and moisture content. Fine or moist particles are typically

more difficult to handle than coarse, dry ones. However, as with angle of repose, one can neither calculate nor infer a bulk solid's flowability directly from its particle-size distribution or moisture content. These may be used as a quality assurance (QA) check against some predetermined acceptance criteria.

Free-flowing versus non-free-flowing. Whether or not a bulk solid is considered free flowing depends to a large extent on the handling system in which it is placed. For example, a material that requires an outlet with the size of 2 in. to prevent arching will flow easily through silos, bins, hoppers and other processing equipment with a larger outlet. However, that same material will arch if placed in a hopper with a smaller outlet. Thus, these terms are relative and are not absolute indicators of a solid's flowability.

Viscosity. Flowing solids generate shear stresses and are able to maintain those stresses even when their flowrate has changed dramatically. Stagnant bulk solids can also maintain shear stresses. Both of these phenomena are in marked contrast to fluids, which require movement in order to generate and maintain shear stresses. Thus, nearly all bulk solids cannot be thought of as having a viscosity, as fluids do (a few examples of exceptions are high-bitumen-content tar sands, or certain rubbery polymers).

Seek more useful parameters

Discussed below are several bulk-solids handling properties that are more relevant to predicting flow behavior. The direct application of these parameters has been proven over the last 50 years in thousands of installations handling materials as diverse as fine chemical powders, dyes and pigments, additive packages, plastic granules, pharmaceuticals, foods and mined ores.

Each of the following properties is discussed along with examples of its application in equipment selection:

- Cohesive strength
- Frictional properties
- Sliding at impact points
- Compressibility
- Permeability
- Segregation tendency
- Friability
- Abrasiveness
- Pneumatic-conveying characteristics

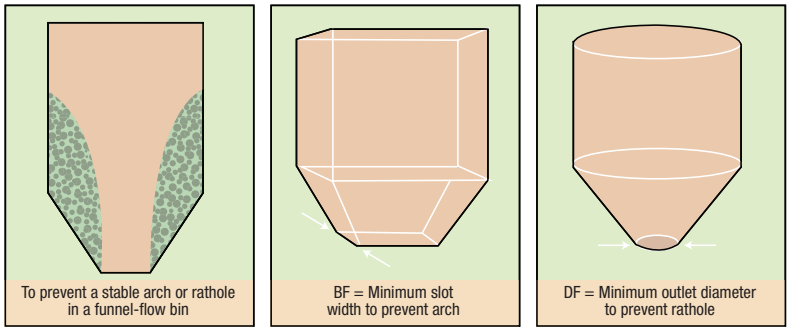

FIGURE 2. A funnel-flow outlet must be sized to prevent both an arch and a rathole

Cohesive strength

Many bulk solids, when poured from a bag, will flow like a liquid. Under these conditions, such a material has no cohesive strength. However, when squeezed in the palm of your hand, it may gain enough strength to retain its shape once your hand is opened.

A similar range of conditions occurs inside bins, silos and storage hoppers. Consolidation pressures range from zero at the surface, to relatively large values at increasing depth within the container. If a solid gains cohesive strength because of the pressures applied to it, an arch or rathole could form.

An *arch* (also called a *bridge* or *dome*) is a stable obstruction that forms over the point of narrowest cross-section of the storage vessel (usually the discharge outlet). The arch supports the rest of the bin contents, preventing discharge.

A *rathole* is a stable pipe or vertical cavity that empties out over the outlet. Material is left stranded in stagnant zones that usually remain in place until an external force is applied to dislodge them.

Cohesive strength can be measured as a function of the applied consolidation pressure. In a laboratory, a sample of the material is placed in a direct shear tester and both compressive and shear loads are applied to simulate flow conditions in a container.

Once the sample has been consolidated, its strength is measured by shearing it to failure. By repeating this procedure under different conditions, the resulting value of strength versus consolidating pressure (called a *flow function*) can be developed. The material's flow function is then used to calculate minimum outlet dimensions — defined later as BC, BP, BF and DF — required to prevent cohesive arches and ratholes from forming. Details can be found in Ref. 1.

Two types of bin flow patterns are possible. A *mass-flow* bin (Figure 1) has a relatively long, tapered discharge section. In mass flow, all of the material is in motion during discharge, so no stagnant regions form.

Conversely, a *funnel-flow* bin (Figure 2) has a relatively short converging section. While storage capacity for a given height is greater in a funnel-flow bin, this geometry allows material in the center to move, while material at the walls is stationary. The resultant stagnant regions may interrupt flow.

For a mass-flow bin with a circular outlet, the minimum outlet diameter needed to prevent arching is expressed as BC (Figure 1, center). Consider a material whose critical outlet dimension, BC, is 12 in. If this material is placed in a mass-flow bin with an outlet diameter of 6 or 8 in., a stable arch will form. Conversely, if the outlet size is 12 or 14 in., a stable arch cannot form, so the material will flow.

Non-conical hoppers are also possible. In general, a wedge-shaped configuration with an elongated outlet is a more forgiving geometry,

which can handle a wider range of conditions for a given material without flow stoppages.

The minimum outlet width required to prevent an arch from forming in a wedge-shaped, mass-flow hopper is expressed as BP (Figure 1, right). For a given material, this value is usually about half that of BC. For example, a material having a BC of 12 in. will also flow reliably in a hopper whose slotted outlet is 6 in. wide.

As a general rule, the length of the slotted outlet should be at least three times its width to minimize the effects of the hopper end walls. Thus, in the example cited, the outlet dimensions would be 6 by 18 in., or longer.

Compared with a mass-flow bin, there are several potential advantages to using a funnel-flow bin. The relatively shallow hopper requires less headroom for a given storage capacity, and since there is minimal flow along the walls, the likelihood of abrasion and particle attrition is minimized.

In general, only the following types of materials will flow reliably in funnel-flow bins:

- Large particle size (≥ ¼ in.)
- Free flowing
- Does not degrade (spoil, cake, or oxidize)
- Segregation either does not happen or does not matter

To prevent an arch from forming in a funnel-flow bin, the minimum width of a slotted outlet must be determined. The critical rathole diameter, DF (Figure 2, right), must also be determined. Ratholing is likely to occur whenever the diameter of the flow channel (set by the size of the outlet) is smaller than DF. As an example, The optimum dimensions for both mass- and funnel-flow bins needed to handle a sample of plastic powder are shown in Table 1.

TABLE 1. OPTIMUM OUTLET DIMENSIONS FOR DEPENDABLE FLOW*

	For bins with unlimited maximum size		As a function of vessel height				
	Mass-flow bin to prevent arch formation	Funnel-flow bin to prevent arch formation	Funnel flow bin to prevent rathole formation				
P-factor	BC, ft	BP, ft	BF, ft	DF at EH = 1 ft	DF at EH = 5 ft	DF at EH = 10 ft	DF at EH = 20 ft
1.00	1.0	0.5	0.5	2.1	6	10	19
1.25	1.0	0.5	0.6	2.3	6	12	23
1.50	1.0	0.5	0.6	2.4	7	14	27
2.00	1.2	0.6	1.0	2.8	9	18	35
P-factor = Overpressure factor			EH = Effective consolidating head				
For a mass flow bin:			For a funnel flow bin:				
BC = Minimum diameter for a circular outlet			BF = Minimum slot width for a rectangular outlet				
BP = Minimum width for a slotted or oval outlet			DF = Minimum diameter for a circular outlet				

*Note: Excerpted from a typical flow-properties-test report, these data for plastic powder (stored at rest for 2 days, at 180°F) illustrate how an analysis of recommended outlet dimensions can dictate bin type.

When consolidation pressures acting on the material exceed gravity alone, the resulting overpressure effects can encourage the formation of an arch or rathole in a bin. Overpressure-induced consolidation can result from vibration, impact on filling, and gas pressure gradients. Table 1 shows how bin dimensions change for a sample of plastic powder, as a function of compaction pressures. Note that for both mass- and funnel-flow bins, the minimum bin dimensions to prevent an arch or rathole from forming are expressed as a function of P-factor.

A P-factor equal to 1 means that gravity alone acts on the material. When P-factor = 1.25, for example, the compacting pressure acting on the material is 25% more than gravity alone. These data can be used to compare practical bin options. From Table 1, one can see that for this material, a funnel-flow bin is impractical, since the required outlet diameter is relatively large in comparison to the vessel size. This would tell the engineer to opt for a mass-flow bin.

The cohesiveness of a bulk solid is a function of the following characteristics:

Moisture. Typically, cohesiveness rises as moisture content increases, although not in direct proportion. Hygroscopic materials can experience significant increases in moisture when exposed to humid air.

Particle size and shape. There is no direct correlation between particle size, shape and cohesiveness. Even so, in most cases, as a bulk solid becomes finer, it also becomes more cohesive and difficult to handle. Angular or fibrous particles are often more cohesive than those that are rounded.

Temperature. A bulk solid's temperature can affect its cohesiveness. For example, many plastic powders become more difficult to handle as their temperature rises. Some materials have more strength at constant temperatures, while others gain cohesive strength as their temperature changes during heating or cooling.

Time of storage at rest. When a material resides in a bin or hopper for a period without moving, it can become more cohesive and difficult to handle. Such cohesion may be caused by settling and compaction, crystallization, chemical reactions and adhesive bonding.

Chemical additives. In some cases, adding a small amount of a chemical additive, such as fumed silica, can cause a cohesive solid to flow more easily.

Frictional properties

Both internal and external friction values are important when characterizing the flow properties of a bulk solid. Internal friction is caused by solid particles flowing against each other, and is expressed by the *angle of internal friction* and the *effective angle of internal friction*. Both can be determined using a direct shear tester.

External friction is expressed as the *wall-friction angle* or *coefficient of sliding friction*. The lower the coefficient of sliding friction, the less steep the hopper walls need to be to get mass flow.

The coefficient of sliding friction can be measured by sliding a sample of material across a stationary wall surface. It is the ratio of the shear force required to cause sliding, to the load applied perpendicular to the plate surface. The arc tangent of this value is the wall-friction angle.

The following variables can affect the internal and external friction values of a bulk solid and are similar to those affecting cohesiveness:

Pressure. Typically as consolidation pressure increases, the effective angle of internal friction decreases. Similarly, the coefficient of sliding friction often decreases as pressure acting normal to the plate increases. However, the internal angle of friction is an intrinsic characteristic of the material, which may increase, decrease, or remain the same as pressure acting on the material increases.

Moisture content. As moisture increases, many bulk solids become more frictional.

Particle size and shape. Typically fine materials are somewhat more frictional than coarse materials, so their flow is often more troublesome. Shape plays a role, in that angular particles tend to interlock with each other and also dig into a wall surface, thereby creating more friction.

Temperature. For many materials, higher temperatures can cause particles to become more frictional.

Time of storage at rest. If allowed to adhere to a wall surface, many materials experience an increase in friction between the particles and the wall surface. Such situations require steeper bin walls for unaided flow.

Wall surface. The initial condition of a surface can play a major role in how materials slide along it. Smoother surfaces are typically less frictional, although this is not always true. Also, as the vessel ages, internal corrosion can roughen the walls, making sliding more difficult.

Friction data are used to calculate bin loads and anticipate sliding on chutes, as discussed in the following:

Calculate bin loads. Frictional properties are also used to predict loads that are applied to the walls of a bin. In the cylinder section of a bin, the loads that are taken by the

vertical walls in shear are affected by the friction that develops between the bulk solid and the cylinder walls. Also, in the hopper section, the loads applied to the sloping walls are affected by the friction that develops between the bulk solid and the wall material, and by the internal friction between particles.

Anticipate sliding on chutes. A chute is used to transfer material from one point to another in a bulk handling system. By definition, a chute is only partially full at any given time (so the discharge rate is equal to or greater than the filling rate). Beyond the impact point (described below), a particle's acceleration on the chute is directly related to the difference between the wall-friction angle of the material and the chute angle. As long as the chute is steeper than the wall-friction angle, particles will continue to accelerate. Otherwise they will slow down and may eventually block the chute.

Sliding at impact points

Two key factors in chute design are the chute angle and the smoothness of the surface at the point of impact. Too shallow or too rough a surface in a chute will impede flow.

The required minimum slope can be determined by placing a ring-type device containing a sample of the bulk solid on a representative sample of the wall surface and applying a predetermined vertical load to simulate impact. Once the weight has been removed, the plate is raised to determine the angle at which the particles began to slide.

All of the factors affecting frictional properties can influence the optimum chute angle, except for time of storage at rest. Since it is against the basis for a chute design to remain full without materials moving through it, that parameter is generally not a design consideration.

Compressibility

In most cases, a material's bulk density varies continuously as a function of the consolidating pressure acting on it. As a result, it is not sufficient to describe a material simply as loose or compacted. Instead, this density-to-pressure relationship can often be expressed as a straight line on a log-log plot.

The following variables can affect a material's bulk density:

Moisture. Higher moisture content usually makes a material more compressible.

Particle size and shape. Often, the finer the bulk solid, the more dense and compressible it is. The shape of the particles can affect how they fit together, as well as their tendency to break while being compacted.

Temperature. Some materials become more compressible as their temperature increases.

Particle elasticity. Elastic materials tend to deform significantly when they are compressed.

Some of the uses of compressibility data are listed below:

Wall-friction angle. Bulk density values at various points in a hopper are used to calculate the pressures acting perpendicular to the hopper wall. After running a wall-friction test, the wall-friction angle is determined for a variety of pressures and used to calculate limiting angles in a mass-flow hopper.

Bin loads. A material's bulk density directly affects the pressures and shear stresses acting on the bin wall. By knowing how bulk density changes with pressure, the forces can be determined more accurately.

Feeder design. To calculate the loads that act on a feeder or gate, one must know the bulk density of the material at the hopper outlet. Knowing this density also helps in sizing a volumetric feeder and choosing its speed.

Permeability

For fine powders, funnel-flow bins often exhibit high discharge rates, but controlling the flowrate is always a challenge. During funnel flow, the flow channel is unstable, and the actual size and shape of the stagnant region is neither well defined nor constant. This channel can change size radically or collapse, creating flowrates that range from no-flow conditions to complete flooding.

Fine powders are more easily handled in a mass-flow bin whose

flow channel is stable and predictable. Since all of the material is constantly moving in a mass-flow bin, the flow channel is set by the shape of the bin.

However, keep in mind that the maximum flowrate of a fine powder through the outlet of a mass-flow hopper is low compared with that of a coarse, granular solid. For fine materials, the expansion and contraction of voids during flow can create an upward air pressure gradient at the outlet of a mass-flow bin. During discharge, this upward gradient acts against gravity, reducing the discharge rate. Such gradients do not usually form with coarser particle materials. Because coarse materials are more permeable than fine ones, air is allowed to flow freely into and out of the voids as they expand and contract.

This phenomenon can be analyzed by considering how gas flows through a bed of powder when a pressure differential occurs across the bed. When the gas velocity is low, flow through the bed is laminar, and Darcy's law can be used to relate gas velocities to gas-pressure gradients within or across the bed. It can be written in the following form:

$$u = -K\left(\frac{dp/dx}{\gamma}\right) \quad (1)$$

Where:

K = the permeability factor of the bulk solid

u = the superficial relative gas velocity through the bed of solids

γ = bulk density of the solid in the bed

dp/dx = the gas-pressure gradient acting at the point in the bed of solids where the velocity is being calculated

The permeability factor, K, has units of velocity and is inversely proportional to the viscosity of the gas. A permeability test is run by passing air (or another suitable gas) through a representative column of solids. The pressure across the bed is regulated, and the rate at which the gas flows is measured.

This approach allows the permeability of the bulk solid to be determined as a function of its bulk density. Figure 3 shows the test results for a sample of plastic powder.

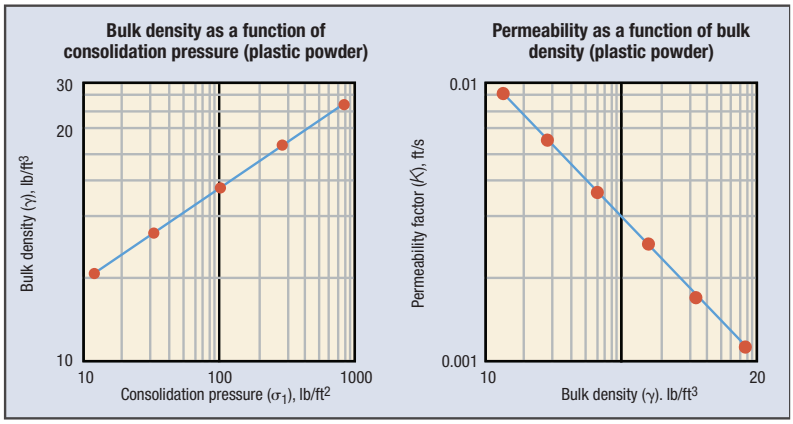

FIGURE 3. Increasing consolidation pressure increases the bulk density and reduces permeability of a material. Unless properly accounted for during bin selection, increased bulk density and reduced permeability can interrupt predictable flow

Because mass-flow bins have stable flow patterns that mimic the shape of the bin, permeability values can be used to calculate critical, steady-state discharge rates from mass-flow hoppers. Permeability values can also be used to calculate the time required for fine powders to settle in bins and silos and to design solids processing vessels to purge, heat, dry or condition bulk solids.

In general, permeability is affected by the following characteristics:

Particle size and shape. Permeability decreases as particle size decreases. Also, the better the fit between individual particles, the lower the bulk solid's permeability.

Moisture content. As moisture content increases, many materials tend to agglomerate, which increases permeability and, consequently, increases the discharge and settling rates.

Temperature. Since the permeability factor, K, is inversely proportional to the viscosity of the air or gas in the void spaces, heating causes the gas to become more viscous, which makes the bulk solid less permeable.

Segregation tendency

Mixtures of solid particles can separate or segregate during handling. This creates costly quality control

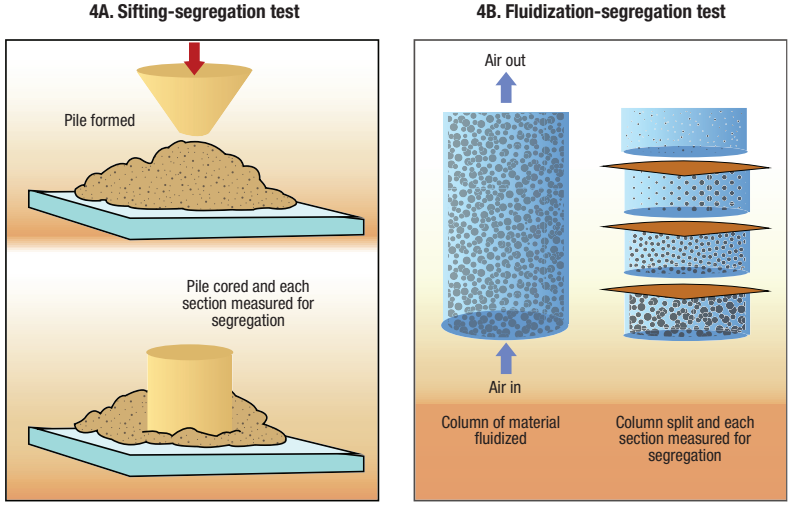

FIGURE 4. Particle segregation inside a hopper can cause process and product quality issues. A material's tendency to segregate can be assessed ahead of time, using segregation tests

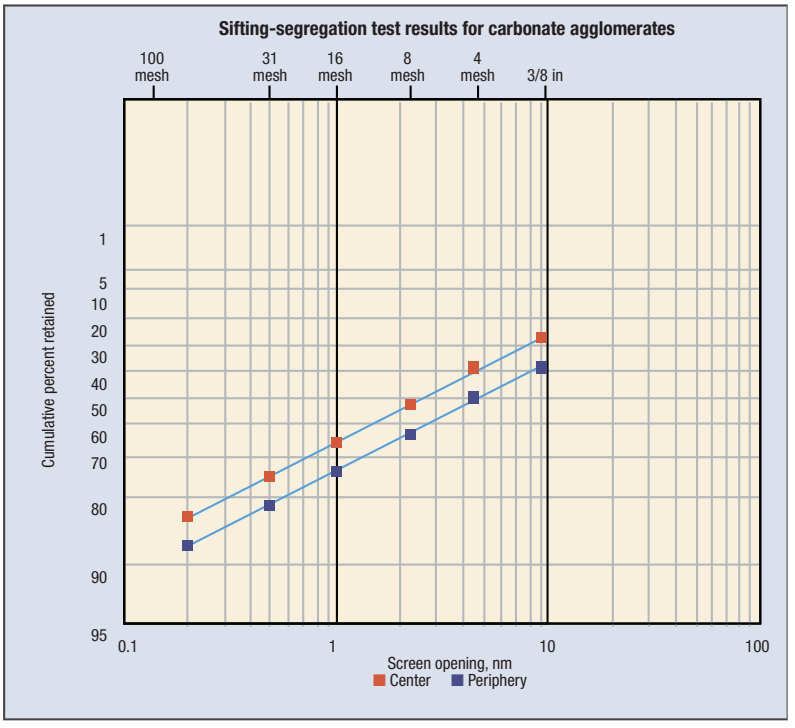

FIGURE 5. Shown here are the results of a sifting segregation test for carbonate agglomerates

problems due to wasted raw materials, lost production, increased maintenance, and higher capital costs. Listed below are the primary mechanisms that account for particle segregation:

Sifting. By far the most common phenomenon in bulk solids segregation occurs as smaller particles move through a matrix of larger particles. For example, when filling a bin, the fines often concentrate under the fill point, while the coarse particles roll or slide to the outer edges of the pile.

Air entrainment (fluidization). In general, fine or light particles are less permeable than coarse or heavy ones. They therefore tend to retain air longer in their void spaces. When a mixture of coarse and fine particles is charged into a bin, it is not uncommon for a vertical segregation pattern to develop, where the coarse particles sink in the bed and the fine particles remain fluidized near the top.

Particle entrainment. The finer and lighter the particles, the longer they may remain suspended in air during filling. These air currents can carry airborne particles away from a fill point to certain areas of a bin, such as toward vents and dust collectors.

Trajectory effects. Air resistance may also affect particles as they fall from a chute. Finer particles have less momentum, so they do not travel as far horizontally when they exit a chute.

A material's tendency to segregate by sifting can be determined by running a sifting segregation test (Figure 4). First a pile is formed under controlled conditions. The pile is then cored to gather a representative sample of particles from its center (under the fill point) and periphery. Each cluster is evaluated for particle-size distribution, chemical content, and other relevant variables in order to determine the degree of segregation that has occurred. Figure 5 shows the results of a sifting segregation test, using carbonate agglomerates. To determine the likelihood of segregation by air entrapment, a tall cylinder containing a sample of the solid is aerated for a short period. After the fluidizing air is turned off, sections of the cylinder are removed, and the contents of each section are analyzed. If the material has segregated by air entrainment, fines will be located near the top, while coarser or heavier particles will be located near the bottom of the vessel.

Variables that can affect the tendency of particles to segregate include the following:

Particle size and shape. Sifting segregation is most likely to occur when the material has a range of particle sizes and when there is inter-particle motion during operation. Generally, particles greater than about 100 μm in diameter are most susceptible to sifting segregation. If most of the particles are smaller than 100 μm, segregation is more likely to occur by air or particle entrainment.

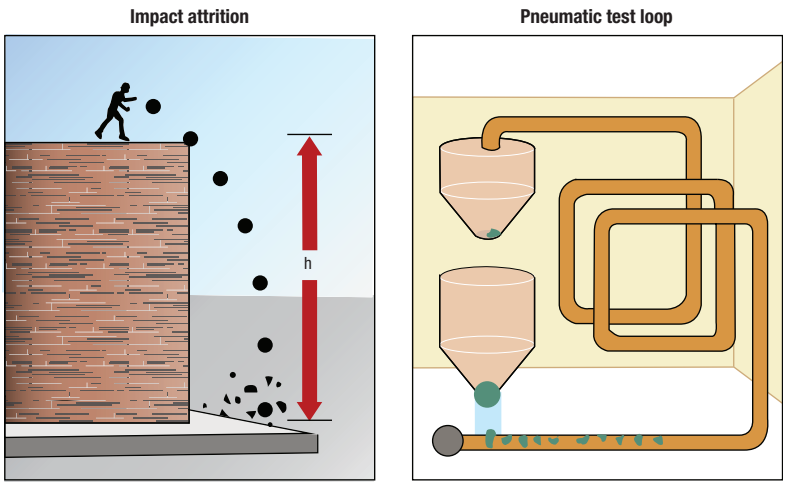

FIGURE 6. Several tests are available for measuring attrition tendency, such as impact attrition (left) and a pneumatic conveying test loop (right)

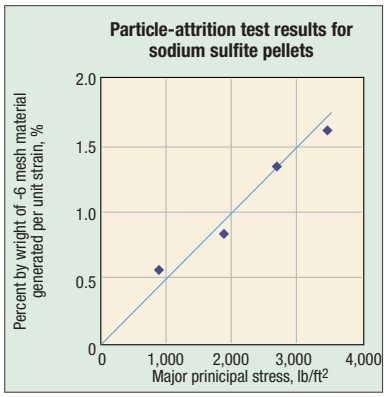

FIGURE 7. Shown here are the results of a rotary-attrition-tester device for sodium sulfite pellets. At high principle stress levels, thee is an increased percentage of smaller particle sizes

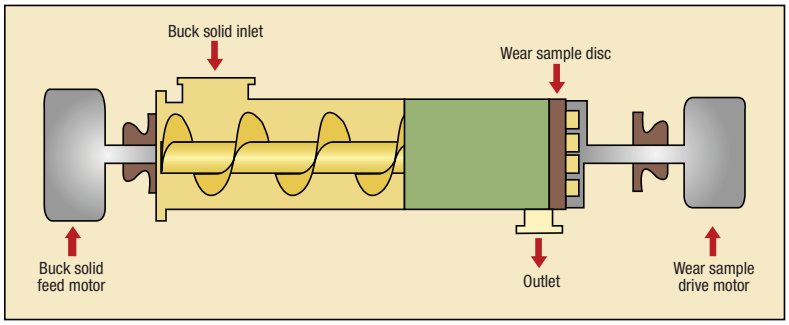

FIGURE 8. This patented wear tester simulates operating conditions to determine the wear rate of bulk solids on a vessel's surface

Cohesiveness. The more cohesive a material, the less likely it is to segregate. Thus, for some materials, increasing the moisture content can reduce the potential for segregation. In general, this makes the material less free-flowing and causes fine particles to stick to coarse ones. Caution is advised, however, since the addition of water or oil can rapidly change a situation from one of free flow to one of no flow.

Bin flow patterns. The type of flow pattern that develops can significantly affect the segregation tendency of materials. Typically, funnel-flow patterns exacerbate side-to-side segregation (such as that caused by sifting) whereas a mass-flow pattern tends to minimize such problems.

Friability

Particle attrition is a major concern in many industries. The breakdown of friable particles may cause unacceptable dust levels, off-specification product, excess product recycle and flow problems. Attrition often occurs as a result of these conditions:

Impact. Particles commonly break at hard impact points, particularly as the material stream is being redirected, such as during bin loading or belt-to-belt transfer points and chutes.

Pneumatic conveying. The amount of particle attrition in a pneumatic conveying line is proportional to at least the square of the particle velocity — if you triple the velocity of incoming materials, the amount of attrition will be increased by a factor of nine, or more. Thus, reducing material velocities can significantly reduce attrition. Attrition is also affected by the number and type of bends in the pipeline. Careful attention should be paid to pipeline size and layout, to minimize particle velocities and the number of direction changes.

Flow through bins and hoppers. Attrition in bins and hoppers occurs where the edges of particles are chipped off or worn away because a weak plane in a given particle is stressed to fracture. As high particle-to-particle contact stresses occur in a bin during normal operation, particles can break. Attrition is not a function of shear strain rate (the velocity of moving particles relative to the wall), but of total shear deformation (actual physical distance) and contact stresses. Breakage is particularly acute in hoppers with converging walls, because significant shears are imposed by changes in velocity at the converging sections. These shear strains are compounded by high contact stresses there.

Mechanical feeders. Screw feeders and rotary valves are notorious for breaking friable materials. Belt feeders are gentler, but they still impart shear stresses that may damage highly friable materials.

Several tests are available to measure attrition tendencies:

Impact attrition. By directing a stream of particles onto a stationary surface, or onto a bed of other particles, the effect of impact on particle-size distribution can be measured (Figure 6, left).

Pneumatic conveying test loop. This setup can be used to determine the optimum velocities and the number of elbows that the material can withstand without suffering too much attrition (Figure 6, right).

Rotary attrition tester. This device consists of an annular shear cell that exposes the material to consolidation pressures while it is being sheared. An example of the test results on sodium sulfite pellets is shown in Figure 7.

The following variables can affect attrition tendencies:

Hardness of both particles and equipment surfaces. The relative hardness influences what happens at an impact point. If the equipment surface is harder than the particles, attrition is likely to occur.

Resilience of particles and surfaces. If either the surface or the material is resilient, the particles are more likely to bounce than break.

Particle size and shape. Large, angular or flaky particles tend to break more than fine or rounded particles.

Impact force. The greater the particle velocity at the point of impact, the more likely that attrition will occur.

Pressures and shear stresses acting on particles in a bin or vessel. The higher the pressures or shear stresses, the greater the degree of attrition that can be expected.

Abrasiveness

Bulk solids flowing in bins, chutes and feeders can wear vessel surfaces. The ability to take preventive measures to predict equipment wear can minimize cost, downtime and maintenance.

Several methods are used to determine abrasiveness. These include the use of rotating disks, sand slurries and rubber-wheel abrasion testers. However, these devices provide only a crude relative measure of the

abrasiveness. They do not simulate the conditions that occur in solids-handling equipment, so using them to predict absolute quantitative wear rates is impossible.

A patented wear tester, shown in Figure 8, simulates the conditions of wear caused by the flow of a bulk solid. During the test, a fresh supply of the bulk solid is continually presented to the contact surface. Pressures exerted on the surface can be controlled and measured, as well as the relative velocity between the solids and the surface.

Shear stresses that develop between the bulk solid and surface are continuously monitored so that changes in the coefficient of friction between the solid and the surface can be noted. Figure 9 shows the results for glass batch (a mixture of dry chemicals) on a variety of vessel surfaces.

Several variables affect the rate of abrasive wear on bulk-solids handling equipment. These include the following:

Hardness of particles and surfaces. Abrasive wear only occurs when the particle is harder than the surface of the material.

Particle size and shape. The ability of a particle to roll on a surface affects its wear characteristics. Both smaller and more angular particles tend to slide rather than roll, so they are usually more abrasive than larger or more rounded particles. Materials with a range of particle sizes are often more abrasive than the fine or coarse fractions by themselves. Hard, angular particles can, of course gouge a surface, thereby accelerating wear.

Moisture. Increased moisture content tends to increase the wear rates. By increasing cohesion, particles are more likely to slide than roll. However, in some instances moisture can have a lubricating effect.

Temperature. If temperature changes enough to influence the hardness of either the bulk solid or the surface, wear rates could be affected.

Corrosion. Unlike the other widely used materials (stainless steel and aluminum), carbon steel is susceptible to corrosion. As carbon steel surfaces age, exposure to moisture or chemicals can combine with abrasive wear to cause a surface to fail prematurely.

Pneumatic conveying

Pneumatic conveying systems are typically categorized as either dilute-phase or dense-phase. In a dilute-phase system, the particles are fully suspended in the air stream and for the most part, individual particles are not in contact with each other. In a dense-phase system, the material moves along the pipeline as a dense bed at low velocity, and individual particles are in contact with each other.

There is a common misconception that all systems rely exclusively on dilute- or dense-phase conveying. In reality, a large grey zone exists between them.

The transition from fully suspended conveying to non-suspension conveying covers a continuous range of intermediate conditions. Many systems operate in this intermediate range.

The key to successful conveying-system design is to understand the properties of the bulk solid and clearly define the requirements of the conveying system. Systems in which the majority of particles are fully suspended in the air stream are by far the most common, because almost any bulk solid can be conveyed this way if the air velocity is high enough. These systems can operate in either pressure or vacuum modes, and are usually designed for 12 to 15 psig systems, and for vacuum conditions of –5 to –7 psig.

Laboratory tests can be used to determine a range of minimum conveying velocities for suspension-phase conveying. Systems that convey material in suspension are usually less expensive and easier to design. However, the drawbacks of suspension conveying are the potential for high particle attrition and pipeline erosion.

On the other hand, lower-velocity non-suspension systems operate at higher pressure. They are usually more expensive, but the benefits may be worth the investment when handling friable or abrasive bulk solids. An assessment of a material's suitability for non-suspension conveying can be derived from an analysis of its permeability and compressibility properties.

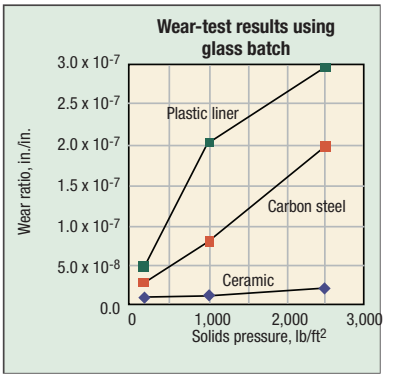

FIGURE 9. This graph shows the wear-testing results for a mixture of dry chemicals on several different vessel surfaces

In general, non-suspension conveying is reserved for the following types of materials:

- Bulk solids that combine high compressibility with low permeability will retain enough air to move in an irregular fluidized-bed pattern through a relatively long length of pipe. Conveying systems for such materials often inject air along the pipeline to maintain fluidization
- Materials that are relatively permeable and non-compressible can often be easily conveyed in non-suspension mode, as discrete plugs

Concluding remarks

Cohesiveness and frictional properties dictate bin and hopper design parameters. Factors such as compressibility and permeability affect how a material flows, and dictate discharge rates from storage vessels. Measuring a material's likelihood to slide at impact points, or its segregation tendency, friability, and abrasiveness can provide important insight as to how to handle it reliably. Meanwhile, a material's behavior also dictates the more troublesome pneumatic conveying system. To minimize problems associated with handling all types of bulk solids, engineers must adopt a systematic approach to characterizing the flow

and mechanical properties of the materials under a variety of operating conditions. ■

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Supply Chain Challenges and Solutions

Transportation is vital to the CPI, so here are some tips to keep your products moving as the market for hazardous-materials shipping continues to tighten

Greg Umstead and Warren Hoppmeyer
Transplace

All shippers strive to keep costs under control while simultaneously running smooth, efficient and time-sensitive supply chains that fulfill orders and satisfy customers. For companies transporting chemicals and hazardous materials (hazmats), this challenge is compounded by the need to comply with a myriad of mandates and regulations, both country-specific and international.

A further obstacle for the chemical process industries (CPI) is the relative uniqueness of their requirements for equipment configuration, container cleaning, and control of prior contents. These challenges, plus a number of others, make it all the more important for CPI managers to place added focus on their supply-chain and transportation strategies. Though this article is written from a U.S. perspective, chemical companies worldwide will recognize many of the issues.

Key challenges in chemicals

It's no secret that there are a number of supply chain challenges in the chemical sector. At the most basic level, the chemical industry is currently going through a period of change and restructuring. According to the consultancy PricewaterhouseCoopers, global sales of chemicals have more than doubled over the last decade, yet transportation availability has not always kept pace.

The next challenge stems from the frequent need to transport hazardous materials. Hazmat handling and transport rules and regulations are well known to chemical manufacturers and processors. And as the primary agents responsible for cradle-to-grave ownership of their products, they need to ensure that these regulations are precisely followed — not just within their own operations, but also by the transportation carriers they select to move their products. Unfortunately, this critical component can be time-consuming, and a more challenging proposition once the order has left the custody of the producer's plant.

FIGURE 1. Though tank trucks account for a large proportion of chemical transportation, tightening regulations and periodic shortages of skilled drivers put pressure on the companies who operate them

Chemical manufacturing depends on raw materials, which are subject to environmental, political and economic influences. The chemical industry recognizes that it can be a target for terrorist attacks, which could potentially disrupt both production and transportation. According to the American Chemistry Council (Washington, D.C.; www.americanchemistry.com), in the wake of the Sept. 11 terrorist attacks chemical producers and their transportation partners have stepped up cooperation with law enforcement agencies, including the Department of Homeland Security and the U.S. Coast Guard, to combat potential threats. This increased emphasis on security adds yet another layer of complexity to the shipping equation.

Additionally, unplanned production issues on both the raw material and manufacturing sides can cause serious headaches for chemical and hazmat shippers. The sheer complexity of chemical manufacture means there is always the possibility of an unplanned shutdown disrupting the supply chain. A company may be forced to manufacture or ship a product from another location, which is likely to be sub-optimal and more costly than the usual arrangement.

Weather-related events, such as hurricanes, road closures, and river closures can disrupt supply chains at any time. Another challenge is cost volatility: for many CPI manufacturers, wide swings in the prices of raw materials can affect not only production costs but also decisions on where to manufacture — and hence logistics.

Road tanker availability issues

The availability of transportation capacity is a constant concern for shippers, regardless of industry. To maintain an efficient supply chain and deliver high levels of service to their customers, companies need to secure truck and rail capacity so that they can move their products as necessary, while remaining competitive (Fig. 1).

The recent global slowdown and fall in the price of oil mean that currently there is surplus capacity of both trucks and qualified drivers. This situation is not expected to last

past 2017, however, after which we may see a return to the tight markets that preceded the recession. Then, increasing demand for capacity from shippers and a lack of available capacity from carriers meant that companies were often forced to pay higher rates to avoid the risk of shipping delays.

Over the long term, more and more long-haul truck drivers have been leaving the industry, as they retired, and have not been replaced. As a result, trucking companies until recently struggled to find enough qualified drivers to keep their fleets at acceptable levels of availability.

Truck drivers for hazardous materials are relatively specialized, so they are particularly prone to scarcity. The U.S. transportation industry as a whole is looking for around 300,000 new drivers a year to replace the shortfall, but even if this number can be found, many will lack experience. The chemical industry generally does not want new drivers hauling hazardous products, so working with bulk carriers on this issue is becoming a significant undertaking.

Additionally, regulatory changes such as the Federal Motor Carrier Safety Administration (FMCSA) Hours of Service (HOS) regulations for truck drivers, and Compliance, Safety, Accountability (CSA) standards, continue to reduce productivity (by 3–5% by most industry estimates) and take more drivers off the road.

Also complicating the picture in the chemical sector are recent government regulations covering driver certification for package carriers transporting certain quantities of bulk liquids in containers larger than 119 gal (450 L). Even if the product is in a container inside a package truck, the driver could soon require the same kind of certification that a bulk tank driver must have. All these issues make it critical for chemical shippers to plan strategically if they are to ensure access to truck capacity and avoid disruptions in the transportation of goods.

Rail freight complications

The U.S. rail tank market, meanwhile, has issues of its own. Changes in standards for car construction and train operation have further complicated an already volatile market.

FIGURE 2. Rail is also crucial for hazardous freight, though in the U.S., recent developments in safety legislation have put pressure on the industry

Following several high-profile accidents involving trains carrying crude oil, the Pipeline and Hazardous Materials Safety Administration (Washington, D.C.; www.phmsa.dot.gov) and Federal Railroad Administration (Washington, D.C.; www.fra.dot.gov) introduced a new DOT 117 tank car specification to replace the existing DOT 111 specification, and new requirements for the systems that control train braking. The new rules apply to "high-hazard flammable trains" (HHFTs): those carrying flammable liquid in a continuous block of 20 or more tank cars, or in 35 or more tank cars dispersed along the train (Fig. 2).

Separate legislation on safety requires all trains to be capable of being stopped remotely in the event of operator error. The necessary positive train control (PTC) systems were originally supposed to be in place by January 1, 2016, but most U.S. rail companies did not meet the deadline. A congressional extension has provided a three-year breathing space, and the American Association of Railroads (Washington, D.C.; www.aar.org) says the industry is committed to implementing PTC quickly and safely.

An alternative to DOT-style rail tank cars is the use of ISO tank containers that can be transferred between road and rail. More recently, tanker trailers have become available that can travel by rail as well as by road. Investments like this can improve the efficiency of long-distance shipping by freeing up truck drivers who would otherwise be occupied for several days at a time.

Overcoming the challenges

In their changing business landscape, and facing the challenges listed above, chemical companies need strategies to help them maintain safe and efficient supply chains. Listed below are a number of ways in which companies can overcome key challenges while improving the performance of their supply chain and hence their entire organizations. Using these tactics can also add operational and financial value within the overall performance of the business.

Expand the transportation mode mix. Shippers often rely solely on road trucks to move their freight. As a result, they can be significantly affected by capacity shortages. By looking to alternate shipping modes, and combinations of modes, shippers can become less reliant on trucks and hence better positioned to combat the effects of capacity shortages. This will also allow them to take advantage of the cost savings and environmental opportunities that comes from using rail. While some people see rail as a slower and less-reliable method of transport, enhancements in rail infrastructure — particularly in the eastern part of the U.S. — have greatly improved the speed and service of rail throughout the country, making it a more vi-

FIGURE 3. Efficient management of freight movements at warehouses and cross-docking points — where goods move between trucks without intermediate storage — is important for smooth operations

able option for shippers today.

Establish long-term supply contracts and multiple sources. Establishing contracts with transportation carriers as well as raw-materials suppliers will help to assure continuity. Additionally, make sure to have multiple contacts for each critical aspect of the business; in other words, work with multiple suppliers and carriers. It's important for companies to work with carriers who know what kinds of equipment and standards are required to transport various classifications of chemicals. Carriers should also train drivers according to the requirements of Federal Regulation 49-CFR, regarding transport of hazmats and sensitive cargo. This reduces risk and builds in a reassuring layer of supply chain accountability.

Plan for risk and disruption. As previously discussed, there are numerous potential disruptions to the chemical supply chain. To be able to respond quickly and efficiently, should these disruptions arise, shippers need to proactively plan and develop contingency plans. Actions might include the use of backup carriers or routes, and the use of secondary facilities (Fig. 3).

Lobby your legislators. Chemical companies have the option of lobbying to make sure the government understands the impact of the regulations and laws it is trying to pass. And if chemical companies participate in lobbying efforts, they will be "in the know" and better able to anticipate future regulatory changes.

Reduce your carbon footprint. Companies in the CPI have an important role to play in reducing carbon dioxide emissions. In the case of logistics, this can be through implementing best practices relative to mileage traveled, route efficiency, and load optimization, while balancing shipment modes, times and costs against customer service expectations. This is destined to become an even bigger issue as government restrictions on truck emissions continue to tighten.

Take advantage of optimization technology. A transportation management system (TMS) can automate the entire supply chain process, as well as help with mode and route selection. The result is added efficiency and cost savings. A TMS can provide 360-degree visibility into every shipment, including automated status updates, milestones, delay alerts and other reporting — all readily accessible from the time of order pick-up to the moment of delivery. This carrier-tracking capability not only allows shippers to keep their customers more informed about planned delivery schedules, but also enables them to make better decisions while shipments are en route, if necessary.

Compliance and visibility are critical for chemical companies, and improvements in these areas can lead to streamlined supply chain operations including improvements in safety, service and costs. A chemical company utilizing a TMS has constant access to critical supply chain data, ensuring that it is using the right carriers at the right price every single time. At the same time, the TMS shows real opportunities to drive cost out of the network and improve safety. A TMS can also provide benchmarking opportunities by strengthening business intelligence capabilities.

Good relationships are vital

Carriers, just like shippers, are always looking for ways to improve efficiency and streamline their operations. This includes being mindful of the companies they work with and keeping detailed metrics for their shipper partners. Some carriers are even scoring shippers on factors such as financial attractiveness; fair auxiliary charges; profile of the freight carried; new opportunities introduced; and how the shipper treats the carrier.

In the past, an abundance of market capacity has given shippers the greater leverage. Carriers have had to compromise, doing anything to get loads. Now, however, changes in industry regulations and the lack of available drivers have caused a tightening of capacity, so carriers are being more selective and strategic about what shippers they work with. As a result, many shippers are even looking for ways to become a "preferred shipper" to their carrier partners.

To gain preferred status, shippers need to understand what drives carrier efficiency. Factors to pay attention to include:

Pay quickly. 70% of carrier expenses are due inside of eight days, so paying carriers in a timely fashion helps to offset rate increases.

Use weekends. Offer freight during off-hours, such as weekends.

Make and honor commitments. Test the market by talking to key partners on key lanes to arrive at a mutual agreement. Then deliver on the agreed terms and expectations.

Manage procurement. After awarding lanes, give sufficient time for the carrier to implement them.

Prioritize partners. Bring new opportunities to your core carriers first.

Treat drivers with respect. Driver-friendly facilities and staff make it easy for drivers to work with your business.

Minimize driver load and unload time. Ensuring that drivers are loaded and unloaded in the least amount of time gives them more hours in transit.

Average daily volumes. Minimize freight volume changes over the year by managing seasonal lane flows and setting up surge capacity.

Manage lead time. Try to increase lead time, measured from the date and time each load is tendered to when it is picked up.

Automate where possible. Use electronic data interchange to communicate and resolve claims and payment issues in a timely fashion.

Stay flexible. Take advantage of multiple service offerings from carriers.

Publish competitive metrics. Understand the competitive landscape and share your data.

Review at a high level. Shipping is vital to your business. Discuss it with top management once or twice a year.

By establishing carrier-friendly practices that promote driver efficiency and productivity, chemical companies can become preferred shippers for their carriers — and be rewarded with capacity.

Two partners, three or four?

Careful carrier selection is especially important right now, when capacity constraints are affecting shippers in all industries. In particular, with heavy reliance on cross-continent flatcar rail and bulk truck transportation, chemical manufacturers face even more of a capacity shortfall than general dry freight shippers, because specialized equipment such as tank trailers and ISO containers, and associated load securing techniques, are required to haul both their non-hazardous and hazmat freight.

Carriers, for their part, want shippers to be partners at every level, working together to drive productivity and efficiency. Recent history has shown that when long-term relationships are sacrificed to price, the outcome can be disastrous. It is imperative that CPI companies be proactive in implementing strategies to create agile supply chains. Such agility allows them to adapt to changes in the market and maintain efficient operations during future transportation capacity shortages.

So far in our discussion of shippers and carriers, we have not mentioned the third point of the triangle: the consignee. The companies that place the orders for the materials being shipped are the driving force for the whole process, yet until now their relationship with the suppliers has largely been "business as usual." Consignees place all of the pressure on the shippers, without helping to solve the problem of how logistics systems should adapt to new demands. In the future, this may change.

Many of North America's largest shippers of chemical products opt to work with qualified third party logistics (3PL) partners. A technology-based transportation management partner can add value in numerous ways, delivering benefits in terms of safety, finance and operations to their shipper clients.

Both hazmat and non-hazardous chemical shippers will continue to face a spectrum of regulatory, economic, political and transportation-related challenges. For many companies, however, a qualified logistics partner offering the right combination of transportation and supply chain experience can ease the way towards optimizing complex logistics processes and deliver both short- and long-term benefits. For manufacturers, the result is increased confidence that the products they ship will arrive on time at their destinations in a safe and timely manner — whether across the state, across the continent, or across the world. ■

Edited by Charles Butcher

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Biological Wastewater Treatment: Maintaining the Needed Microorganism Population

Activated sludge processes are inherently complex. Proper system design, operation and maintenance are essential to adequately break down target organic materials

Bart Peeters and **Frank De Groof,** Monsanto Europe N.V
John Pugh, Monsanto Co.

Since its discovery more than 100 years ago in 1914 by Ardern and Lockett [*1*], the activated sludge process has been (and still is) the most widely used process to treat domestic and industrial wastewater [*2,3*]. It involves the creation and management of a human-engineered and managed ecosystem. Biological reactors support desired microbial populations, particularly bacteria in flocculated forms known as activated sludge flocs (Figure 1). Such flocs are grown as the microbial population, and convert biodegradable organic substances in the wastewater inlet stream into carbon dioxide and new biomass.

While a typical activated sludge wastewater treatment plant (WWTP) has a relatively simple layout, the underlying biodegradation processes involve exceedingly complex phenomena, which proceed in a series of enzymatic reactions.

Facility operators often overlook the importance of establishing the right colony of microorganisms in an activated sludge system to target the biodegradable organic pollutants at hand

Enzymes play a key role

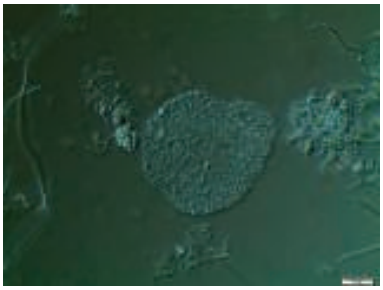
Enzymes mediate virtually all biochemical reactions in living cells where covalent bonds are formed or broken [*4*]. Enzymes are proteins that act as in vivo catalytic agents within the cell, forming complexes with the organic substances. The enzymes convert organics to specific products, while the enzymes are released to repeat the same reaction [*5*]. Enzymes are useful, in that they accelerate the most elaborate chemical transformations that would otherwise occur at only imperceptible rates. Two types of enzymes are involved in this biodegradation process — namely extra- and intracellular enzymes:

- Extracellular enzymes are excreted at the cell surface by the microorganisms, and they help to break down the pollutants outside the cells into smaller metabolites that are small enough so that they can permeate through the cell walls
- Transported smaller fragments are integrated into the microbial metabolism; that is, they are further oxidized to provide cell energy, or are transformed by intracellular enzymes into new "building blocks" to be used in cellular synthesis [*5*]

Substrate-specific enzymes

This biodegradation process has further complexity. Next to so-called constitutive enzymes that are synthesized during all the cellular life independently of the presence of specific substrates, so-called inducible enzymes are only produced when a specific molecular signal (resulting from the presence of a specific substrate) is recognized by the cell [*6*]. In this case, the microorganisms must produce substrate-specific enzymes to be able to break down the target substrate. What's more, these induced enzymes are not synthesized instantly; rather, a latent period is necessary to set up the cell apparatus [*6*].

Hence, to address hard-to-treat wastewater or to biodegrade target constituents in complex wastewater



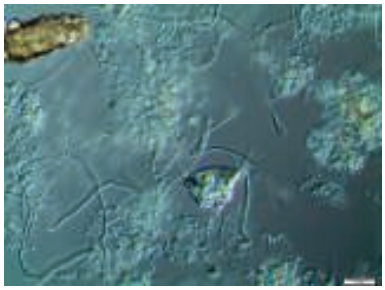


FIGURE 1. These two microscopic images of activated sludge (magnification 200x) show individual bacteria growing as colonies, forming sludge flocs. Some bacteria grow in longer strands (filaments) extending out of the flocs. In the image on the right, the bright particles are precipitated inorganic $CaCO_3$ salts

streams, it is necessary to develop and maintain tailored, acclimated microbial populations within the sludge. The sludge retention time (SRT) plays a pivotal role in this.

Sludge retention time

The SRT (also referred to as the mean cell-retention time, or MCRT) is an important operational parameter that represents the average time spent by the sludge in the biodegradation basin. The SRT is controlled by means of the sludge-wasting rate. For example, in the case of an activated-sludge system that has an inventory of 60 tons of sludge solids, and the total wasting rate is 2 tons of sludge solids per day, the SRT amounts to 60/2 = 30 days. Note that in cases where there are solids losses via clarifier overflow, this additional sludge-removal mechanism needs to be taken into account, as well.

Example of EtS removal. The key role of the SRT, in terms of pollutant removal, will be exemplified here by the removal of ethyl sulfate (EtS), based on a 2-year follow-up at Monsanto's WWTP in Antwerp, Belgium. The biological removal of poly(vinyl alcohol) (PVA) is also discussed, to further emphasize that certain conditions are needed to create a friendly environment for the target microorganisms (Figure 2).

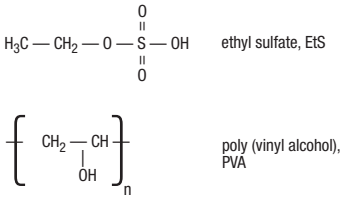


FIGURE 2. The biodegradation of ethylsulfate (EtS) needs specialized bacteria to cleave the bond between the ethyl and sulfate group. Likewise, the long-chain polymeric molecules of poly-vinyl alcohol will only be broken down by microorganisms that are adapted to do so

Different analytical techniques are used to monitor EtS and PVA in wastewater during activated-sludge treatment, including the following:

- EtS — Reagent-free ion chromatography (RFIC) with a hydroxide gradient and conductivity detection
- PVA — Reversed-phase ultra-performance liquid chromatography (UPLC) with single-quadruple, mass spectroscopy detection

For both components, quantification was done with an external standard calibration. The detection limit is 500 parts per billion (ppb).

Figure 3 presents the data related to the EtS concentration in the feed stream, and in the WWTP's final effluent, as well as the EtS removal efficiency. At the beginning of the timeframe represented in Figure 3, monthly analyses (depicted as two black dots, for June and July 2012) showed no EtS being present in the treated effluent, as usually experienced at this WWTP.

Then, because of an excessively high sludge inventory in the system — due to a high fraction of $CaCO_3$ salt precipitating from the water and being enmeshed in the flocs (thereby increasing the amount of total solids in the biodegradation basin), it became an operational necessity to significantly increase the sludge-wasting rate, starting in the beginning of August. As a result, the SRT, calculated daily and depicted in dark blue color in Figure 4, dropped dramatically from typically 30–40 days to only 10 days.

The next detailed analysis of the effluent showed a residual EtS concentration of 175 ppm at the end of September (indicated by the letter A in Figure 3), with a removal efficiency of barely 50% (shown in red color in Figure 3). At that moment, the sludge-wasting rate was lowered again, in line with a theoretical SRT of about 30 days since the end of September.

About two weeks after this corrective action was taken (note that the SRT does not increase instantly as soon as the wasting rate is reduced), the EtS concentration in the effluent was again 0 ppm (the frequency of EtS analysis was increased to a daily analysis for this study). However, a next (still necessary) stage of higher sludge-wasting rate was initiated at

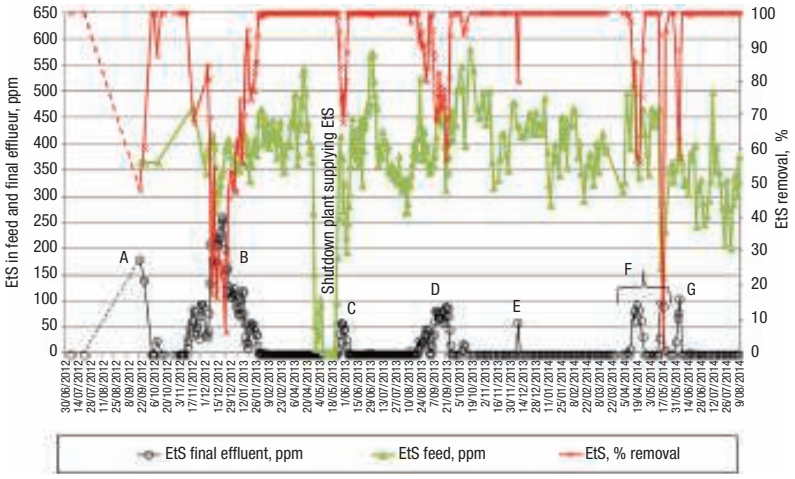


FIGURE 3. Shown here is the ethylsulfate (EtS) concentration in the feed and final effluent at one facility over time, together with its removal percentage. In periods A and B, the EtS removal was poor due to the insufficient sludge age (see Figure 4) and, hence, unadapted sludge

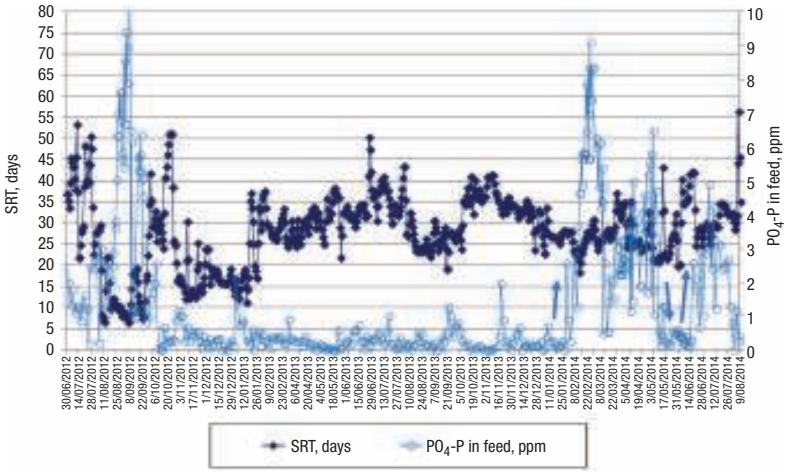


FIGURE 4. Shown here is sludge-retention time (SRT) and phosphorus concentration contributed by phosphate in the feed (PO_4-P) over time. At the left side, two periods with a very short SRT of 10 and 15 days can be discerned which resulted in poor EtS removal as depicted in Figure 3. At the right side, the light blue arrows indicate PO_4-P increase (or decrease) in the feed which yielded a higher (or lower) removal of PVA as shown in Figure 5

the beginning of November, yielding an SRT this time of about 15 days.

Two weeks later, EtS started appearing in the final effluent (this is shown in Figure 3, as the beginning of period B).

A month later, in the middle of December 2012, the EtS removal reached only 20%. As a consequence, the sludge-wasting rate was lowered once again, to stick to an SRT of roughly 30 days (from January 25, 2013 onward). This was only possible by taking into service an additional biodegradation basin that provided additional sludge-inventory-management capabilities. With all of these changes, about 10 days later, 100% EtS removal was achieved again.

The above-described effect of the SRT on EtS removal illustrates well that adapted microorganisms are needed to efficiently degrade EtS. A higher SRT allows: (a) acclimation time for substrate-specific enzyme activity to be turned on and, (b) the populations of slow-growing bacteria to proliferate in cases where the SRT is higher than the regeneration time. Essentially, if the bacteria of concern do not grow fast enough to replace themselves, they can be washed out with an excessively high sludge-wasting rate. When this happens, the biodiversity decreases and some specific functions of the biodegradation process are no longer supported.

Additional observations in practice. A series of other observations further underscore the importance of maintaining the needed microbial population. After the manufacturing plant that was supplying EtS to the WWTP was shut down for two weeks in May 2013 (this is indicated in Figure 3), the sludge needed about 2 weeks to again completely degrade the newly supplied EtS (see period C in Figure 3, following the feed's EtS-depletion period).

Further, the reduced EtS removal (indicated in period D in Figure 3) corresponds well with a slightly lower SRT. Likewise, the final EtS peak around the end of May 2014 (depicted in period G in Figure 3) correlates well with the preceding 3-week period that had a reduced SRT of 20 days. Conclusively, an SRT of roughly 30 days seems to be a prerequisite for appropriate EtS biodegradation. This is one of the same order of magnitude as the SRT of approximately 3 weeks for almost complete EtS biodegradation that was reported in Ref. 7 and determined here by using a standardized OECD (Organization for Economic Cooperation and Development) 301 F respiratory test.

The short-term EtS peak in the final effluent indicated by E in Figure 3 has not yet been discussed. This peak emphasizes again the complexity inherent in biological wastewater treatment. This short-term reduced EtS removal correlates well with a shock load of aniline that reached this WWTP, which seems to have affected the EtS breakdown at that moment. A possible cause for the observed EtS set-ups (indicated with F in Figure 3) is, however, not known — once more highlighting the inherent complexity of wastewater treatment based on biological processes.

Before the removal of PVA will be discussed, it must be mentioned that after the first period A in Figure 3 of low EtS removal due to the reduced SRT, the standard applied phosphate dosing in the feed (data depicted in light blue in Figure 4)

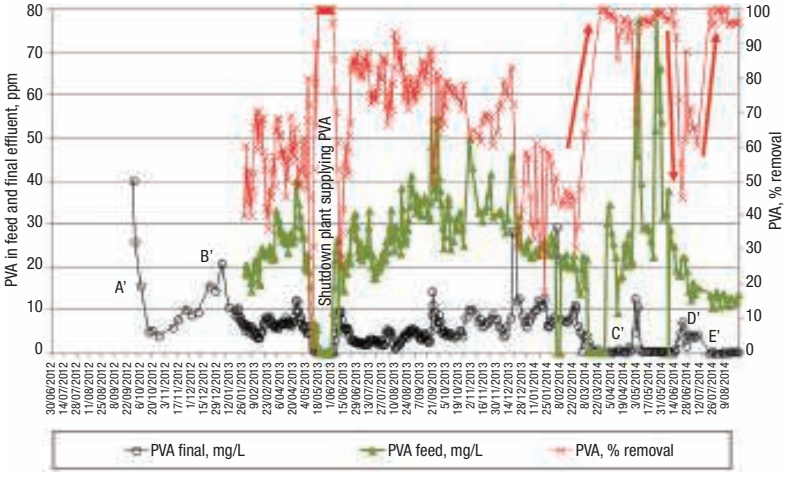


FIGURE 5. Poly-vinyl alcohol (PVA), concentration in the feed and final effluent, together with its removal efficiency. The red arrows show variations in the PVA removal induced by the PO_4-P changes depicted with light blue arrow in Figure 4

was stopped, because phosphorus-containing molecules were found at that time in the final effluent — indicating reduced biological treatment efficiency. Because of the low permitted concentration for discharge of total phosphorus from the facility, the phosphate dosing was stopped at that time.

Enabling the microorganisms

Figure 5 presents the data for the PVA follow-up (over the same time scale as the EtS followup). In the period where the EtS removal was the worst (end of 2012, beginning of 2013, corresponding to periods A and B in Figure 3), the PVA concentration in the treated water also turned out to be higher than would be the case later on during this detailed study, as indicated with A' and B' in Figure 5.

One explanation for this can be found in the too-short SRT in these two periods (10 and 15 days, respectively), which caused the low EtS-removal efficiency, as discussed earlier. As is the case for EtS degradation, the system must maintain appropriately adapted, acclimated microbial populations, and this demands several weeks; a too-low SRT impedes appropriate bacterial growth in the system of "degradation specialists" with longer generation times, which have the capability to biodegrade specific target molecules, such as PVA.

The data depicted in Figure 5 demonstrate a PVA-removal efficiency varying between 50% and 80% from the beginning of February 2013 until February 2014. During this period, SRT was kept between 25 and 40 days (Note: from February on, the PVA was additionally analyzed in the feed to the WWTP). The observed variation in PVA removal could be attributed to possible small changes in the structural characteristics of the PVA, which is known to affect the activity of several PVA-degrading enzymes, and hence the rate and extent of polymer biodegradation.

Then, around the beginning of March 2014, the PVA in the final effluent fell from 2–10 ppm to a baseline of 0 ppm (see Figure 5), indicating complete removal of the PVA. This remarkable observation correlates well with the WWTP's phosphate addition (to serve as a source of the nutrient phosphorus (P), for the microorganisms) since the beginning of February 2014. It is known that a P-to-C ratio in the feed that is too low can cause loss of treatment efficiency with activated sludge processes. Since the "optimal" ratio depends on the particular biological process, it needs to be tailored to each individual wastewater [5].

It appears that the amount of P in the feed before March 2014 was not enough to attain complete PVA removal, whereas complete EtS removal was still achieved with the lower-P system condition. The period indicated with letter D' in Figure 5, where the PVA removal is clearly lower, confirms the need for extra P nutrient in the feed of this WWTP to ensure the complete removal of PVA. This period of temporarily reduced PVA removal correlates well with the temporary cessation of phosphate dosing that had been initiated about 20 days before. Complete PVA removal was restored again in the period marked E' (Figure 5), after the extra P dosing was restarted.

The short-term reduction in PVA removal, as indicated with C' in Figure 5 (April 5–19, 2014), coincides with an observed — but equally unexplained — short-term lower EtS removal. Something had caused a short-term effect on the biological working of the activated sludge, as exemplified by the lower PVA- and EtS-removal rates.

It is important for facility owners and operators throughout the chemical process industries to recognize that in addition to degradation generalists, degradation specialists are needed to design systems that will reliably biodegrade hard-to-degrade pollutants. Biological wastewater treatment is an inherently complex process. Factors such as ensuring a sufficient long sludge (SRT) age and an abundance of nutrients such as P are prerequisites to augment the biological removal of specific components. ■

Edited by Suzanne Shelley

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About 900 exhibitors will present the latest technologies for processing, analyzing and handling powder and bulk solids at Powtech 2016 (April 19–24; Nuremberg, Germany). In addition to the exhibition, there will be three trade forums with non-stop presentations in the exhibition halls (many of them in English). The 30-minute slots and panel discussions will address current topics in the industry. The Pharma.Manufacturing.Excellence expert forum, organized by APV (the International Assn. for Pharmaceutical Technology), will focus on trends and challenges in pharmaceutical manufacturing, including continuous production, tableting and testing, 3-D printing and serialization. The Powtech Expert Forum (Hall 2) will provide presentations on process automation, particle analysis and measurement technology. The international IND EX Safety Congress will be held at Powtech on April 20. Explosion protection experts will be on hand to explain different legal requirements by region and the latest approaches for greater explosion protection.

Alongside Powtech, the Nuremberg Exhibition Center will host Partec, the international congress for particle technology. Partec brings together leading particle engineers and scientists to share knowledge about the latest developments in particle formation, agglomeration and coating processes, as well as measurement techniques and various industrial applications for particles.

What follows is a small selection of products that will be presented at the Powtech exhibition.

A smart system for suppressing explosions

The new intelligent detection system, SmartDS (photo), provides secure explosion detection with high false-alarm immunity. SmartDS uses two dynamic pressure sensors in AND configuration and a "smart" calculation of the expected rate of pressure rise based on experimental data and 25 years' experience. In the event of an explosion, the SmartDS rapidly analyzes the pressure data and actuates the active explosion-suppression system. The system is designed to detect the pressure development during an explosion and within milliseconds discharge an explosion suppressant into the enclosed space before destructive pressures develop. Quick, safe and exact measuring is an essential part of the system, says the company. Hall 1, Stand 319 — *IEP Technologies GmbH, a Hoerbiger Safety Solutions Co., Ratingen, Germany*
www.ieptechnologies.com

'Easy Control' makes these roller compactors Industry-4.0 ready

With Easy Control (photo), remote access via smartphone or tablet allows the user a permanent, mobile and direct access as well as transparent and quick operation of more than one roller compactor. By means of a protected login using any current type of smartphone or tablet, you can directly see the process. This flexibility increases the availability of qualified staff and operators, and at the same time saves costs, says the company. The automatic-logout function ensures that only one authorized user has access to the machine at the same time. The user gets a detailed view of the process, supported by zoom and scaling functions on small displays, and can also save trends, parameters or other details via USB interface or printer. Hall 1, Stand 220 — *Alexanderwerk GmbH, Remscheid, Germany*
www.alexanderwerk.com

Select different milling processes from one platform

FreDrive (photo) — the new universal platform for special applications — is a unique, revolutionary milling platform concept. Within minutes, up to five different grinding heads can be attached, either for primary crushing, de-agglomeration, granulation, fine grinding or control screening on the universal platform, which combines the control and drive units. Changeover to a new grinding process takes a few minutes; the operator simply loosens the Tri-Clamp, changes the milling head, and reattaches the Tri-Clamp. With FreDrive, users can mill sticky, hard, or crystalline powder with widely varying product characteristics gently and problem-free. All applica-

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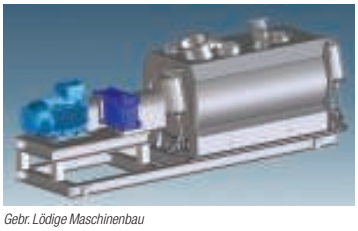
IEP Technologies


Alexanderwerk


Frewitt Fabrique de Machines SA

Italvacuum

Freeman Technology



Gebr. Lödige Maschinenbau

tions that require a mill with screen calibration (including ATEX Zones 0/20 and 1/21) are covered. The FreDrive can be mounted on a mobile lifter that meets all standards of the pharmaceutical industry. Hall 1, Stand 343 — *Frewitt Fabrique de Machines SA, Granges-Paccot, Switzerland*
www.frewitt.com

A vacuum pump with many benefits

The Saurus939 vacuum pump (photo) is said to offer unrivaled performance in all the main chemical and pharmaceutical processes, ensuring total recovery of extracted solvents, even in severe operating conditions. The pump features the innovative LubriZero system, which delivers a metered injection of oil (about 10 g/h) that guarantees an effective barrier from even the most aggressive solvents, considerably increasing the duration of the perfect cylinder-piston coupling and hence the working life of the vacuum pump, says the company. Saurus939 handles aggressive and corrosive solvents, powders and condensates, as well as distillation by-products, and is designed and manufactured to work 24 h/d with minimum operating costs, thanks to a low-energy motor, negligible oil consumption and easy, immediate maintenance. Cylinder, pistons, piston rings and head are made of special anti-acid cast iron. The other components are made of cast iron, special steel and PTFE with special charges. Hall 3A, Stand 412 — *Italvacuum s.r.l., Borgaro, Italy*
www.italvacuum.com

A new powder tester to be introduced at Powtech

The new Uniaxial Powder Tester (UPT; photo) provides an accurate and repeatable measure of the unconfined yield strength (UYS) of a powder to assess and rank flowability. It is quick, reliable and easy to use, delivering value to scientists, process engineers and quality-control analysts working in a diverse range of bulk solids handling industries, says the company. Available in manual and advanced versions, the UPT offers a low cost, powder-testing solution. Alongside the UPT, the company continues to provide a comprehensive powder characterization solution in the FT4 Powder Rheometer, a unique universal powder tester that uses patented dynamic methodology, automated shear cells and bulk property tests to quantify the flow properties of powders. Hall 4, Stand 547 — *Freeman Technology Ltd., Tewkesbury, U.K.*
www.freemantech.co.uk

This mixer feeds, mixes and discharges very quickly

The quick-emptying mixer of type SEM 3000 (photo) is equipped with an extra large discharge opening along the entire length of the drum. The large discharge opening ensures an almost residue-free discharge of the product in only two seconds. This is especially suitable for applications requiring high throughputs in combination with batch operation. In addition to prompt discharging, the unit provides quick feeding and short mixing times. Up to 25 batches per hour can be processed. The batch mixer operates with the principle of the mechanically generated fluidized bed. Ploughshare Shovels rotate as mixing elements on the mixing shaft in the horizontal, cylindrical drum of the SEM 3000. In this way, powdery, grainy and fibrous products are moved in three dimensions, whereby all of the product is constantly involved in the mixing process. The mixing elements are specially shaped to lift off the product away from the drum wall and to prevent particles from being crushed, ensuring a particularly gentle processing of the product. The new SEM is available in four sizes with drum volumes from 1,600 up to 3,000 L. Hall 1, Stand 517 — *Gebr. Lödige Maschinenbau GmbH, Paderborn, Germany*
www.loedige.de

Energy-efficient solutions for compressed air and vacuum

The economical, oil-free compressors of type ZE 5-6 (photo, p. 29) are now also available with air cooling. Especially suitable for low-pressure applications (up to about 4 bars), they are commonly used in processing of powder and bulk solids. All machines are available with an integrated frequency inverter to adjust the flowrate to meet the the demand. The range of the series (ZE 2 to 6) have motors with power ranging from 37 to 500 kW, delivering flowrates of 350 to 7,200 Nm^3/h. The direct-drive of the ZE machines is said to achieve a much higher efficiency than belt-driven com-

pressors, and their oil-cooled, double-element block saves energy. With air cooling, no cooling-water connection is required, which simplifies installation. Hall 3, Stand 524 — *Atlas Copco Kompressoren und Drucklufttechnik GmbH, Essen, Germany*
www.atlascopco.de

High rates achieved with this centrifugal sifter

The new high-capacity centrifugal sifter Model K1350 (photo) removes oversize foreign matter and agglomerates from on-size material at rates up to 100 ton/h. The K1350 features an easy-to-clean cantilevered three-bearing shaft design with bearings at the motor end of the shaft and on the exterior of the discharge end cover, providing maximum support for heavy loads. When the end cover door is opened, the shaft cantilevers on a third in-board bearing, allowing the screen cylinder and helical paddle/feed screw assembly to slide freely from the shaft end for rapid, thorough wash down. An exclusive "forward and lift" access door on gas struts improves interior access for cleaning, inspection and maintenance. The sifter can be configured for gravity-fed applications, or dilute-phase positive- or negative-pressure in-line pneumatic systems. Hall 4A, Stand 525 — *Kason Corp., Millburn, N.J.*
www.kason.com

This laser-based particle sizer covers a wide range

Due to the particularly wide measuring range of 0.01 to 2,100 µm, the Analysette 22 NanoTec (photo) is a universally applicable laser-based system for efficient particle-size analysis down into the nanometer scale. The sizer is based on static light scattering, which is said to be ideal for fast analysis. The system is suitable for use in both production and quality control, as well as in research and development. The modular design guarantees fast, dry and wet dispersion due to a wide range of dispersion modules. Hall H2, Stand 218 — *Fritsch GmbH, Idar-Oberstein, Germany*
www.fritsch.de

Established equipment for making softgel capsules

This company has developed a system for making hardshell and softgel capsules (photo). To keep the heat-up times short and make product of high consistency, good mixing is important. In particular, mixing and dispersing technology has been designed to guarantee homogenous distribution of substances as well as product stability. Traditional softgel capsule shells are made of animal-based gelatin, with all ingredients added to a gelatin melter. To keep the heat-up times short and make product of high consistency, a strong top-to-bottom mixing is essential. For the best mixing performance, the company's Paravisc axial flow impeller is used, which outperforms an anchor impeller. The Paravisc is capable of moving entrapped air bubbles of all sizes to the surface, efficiently and without breaking them up. Switching from a traditional gelatin cooker with an anchor impeller to a system with a Paravisc impeller more or less doubles the productivity, says the company. For vegetarian shell material, the formulations are harder and resistant to higher temperatures than the traditional animal-derived gelatins. The S-JET homogenizer is very well suited for this task because of its ability to pump even the thickest materials at a high rate. Hall 2, Stand 346 — *Ekato Group GmbH, Schopfheim, Germany*
www.ekato.com

This tablet press is cool, fast and clean

The KTP 420X tablet press reliably cools the process area to below 30°C, which is why the technology is ideal for processing temperature-sensitive medications. Special compression rollers, bolts and bearings ensure low mechanical friction while the efficient cooling of the V-ring seals and drives prevents the formation of heat. The system has a maximum output of 360,000 tablets per hour. The hermetic separation of the compaction area and the machine compartment means no tablet dust gets into the bottom of the machine. The patented punch bellows protect the tablets from contamination with lubricants. Hall 3, Stand 430 — *Romaco Group, Karlsruhe, Germany*
www.romaco.com ■

Gerald Ondrey

Atlas Copco Kompressoren und Drucklufttechnik

Kason

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Ekato Group

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Chemical Engineering Features Report Guidebook- 2014

CHEMICAL ENGINEERING
ESSENTIALS FOR THE CPI PROFESSIONAL

Chemical Engineering's Feature Reports provide concise, factual information that aids in solving real problems. The practical, how-to orientation of these articles ensures that they can be directly applied to chemical engineers' daily jobs. Each article applies to a relatively broad section of the chemical process industries as opposed to focusing on just one niche.

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- Unlocking the Secrets of Plate-and-Frame Heat Exchangers
- Industrial Control Systems Security: The Owner-Operator's Challenge
- Fine Tune the Design of Sour-water Strippers Using Rate-based Simulation
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- Control Valve Selection: True Cost Savings Are Available
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- New Horizons For Dividing Wall Columns
- Advanced Control Methods for Combustion
- Magnetically Driven Pumps: An overview
- Modern Water-Treatment Challenges
- Challenges of Drying Sticky Wastewater Sludge
- Pressure Transmitter Basics: Selection Guidelines
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- Solids Handling: Using Flowsheet Simulation to Improve Process Design
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Show Preview

Over 3,300 industry professionals will attend the International Powder & Bulk Solids Conference and Exhibition, which takes place May 3–5 at the Donald E. Stephens Convention Center in Rosemont, Ill. Hundreds of industry suppliers will be exhibiting their products, which span all types of equipment for handling and processing solids. In addition to individual exhibitions, two presentation theaters on the expo floor will host presentations on a wide variety of topics, as well as product demonstrations. Throughout the three days, the Education and Training Conference will presentations on a number of practical topics, including powder and bulk-solids flow management; pneumatic conveying design; explosion suppression; segregation of particles; and more.

The following is a small selection of the products that will be exhibited at the show.

A spray-drying nozzle for clog-resistant, low-flow applications

This company has introduced a multi-orifice spray nozzle that increases flowrates while maintaining the same drop size. The latest addition to the SprayDry SK Series of low-flow spray nozzles, the 3SK model (photo) uses three orifices and cores to increase production and improve dryer efficiency. Ideal for commercial spray drying of powders in the dairy, food processing, chemical, biochemical and pharmaceutical industries, the SprayDry 3SK nozzle features a slotted-core design that produces consistent particle sizes. The result is a hollow-cone spray pattern with uniform distribution of the smallest drop sizes available, which evaporate more quickly to save on heat and energy costs. With an anti-bearding design that reduces build-up in the nozzle orifice and an optional 100-mesh strainer to prevent clogging, the SprayDry 3SK is designed to extend wear life and reduce maintenance time. It features spray angles from 45 to 90 deg and a maximum pressure of 7,000 psi. Booth 1303 — *Spraying Systems Co., Wheaton, Ill.*
www.spray.com

Less manual effort required for this quick screen-change system

A new Air-Lift system integral to round vibratory-screening frames (photo) is said to enable cleaning, inspection and screen changes four- to five-times faster than alternative systems, while requiring 75–85% less manual effort, says the manufacturer. The lightweight device consists of two vertically mounted air cylinders that are located on opposing sides of any circular separator and affixed to mounting brackets on the lower and upper screening frames. To operate, a quick-disconnect clamp connecting the frames is removed and a remote air valve is actuated, raising the upper frame. The procedure is reversed to reconnect the chambers. One entire raise/lower cycle including quick-disconnect/connect of the frames, requires only several minutes, says the company. Other features include a safety lock-out that locks the frames in the open or closed position when the upper screener housing is raised or lowered, and safety bars that prevent the housing from accidentally descending while in a fully raised position during screen changes or washdown. The Air-Lift device is available on any of the company's new screeners, and can be retrofitted to any circular vibratory screener of any make or model from 48 to 84 in. (1,220 to 2,135 mm) in diameter, including screeners having single or multiple decks, screens with or without center holes or anti-blinding devices. Booth 2107 — *Kason Corp., Millburn, N.J.*
www.kason.com

A wide range of bulk solids is handled by this versatile feeder

The Mechatron dry-material feeder (photo) has all the unique design features that manufacturers require for their processing applications. Complete disassembly from the non-process side of the feeder eliminates the need to remove upper extension hoppers, bins, bulk bags and intermediate bulk containers (IBCs) to clean or maintain the feeder. Flexible or all-stainless-steel hoppers are available to accommodate any unique dry-material feeding application. Mechatron feeders handle a wide range

Spraying Systems

Kason

Schenck Process

Flexicon

Material Transfer & Storage

MECO Seal

of volumetric or gravimetric feeding applications for bulk solid materials, such as TiO_2, wood flour and carbon black. Additionally, the Mechatron can achieve feedrates from 0.002 to 1,100 ft^3/h. Booth 1429 — *Schenck Process LLC, Whitewater, Wis.*
www.accuratefeeders.com

This bulk-bag discharger has a hopper-shuttle system

The new Bulk-Out Bulk Bag Discharging Station (photo) prevents cross-contamination during material changeovers, while eliminating down-time associated with cleaning of hoppers. Beneficial for applications involving food allergens, pigments, flavorings and other contamination-sensitive materials, the discharger features a shuttle system that allows a hopper that has been used to be exchanged for a clean, dry hopper in less than one minute. Each hopper is equipped with a stainless-steel rotary valve that meters material into process equipment positioned below the mezzanine. Once empty, a hopper can be rolled within two C-channels to either side of the central filling position for sanitizing offline. Integral support rails on the rotary valve allow the rotor assembly to separate from the valve body for cleaning of all material-contact surfaces without the use of tools. The discharger portion of the dust-tight system employs a Spout-Lock clamp ring that secures the clean side of the bag spout against the clean side of the discharger. A Tele-Tube telescoping tube promotes material flow through the bag spout by maintaining constant downward tension on the clamp ring as the bag empties and elongates. Additional flow promotion is afforded by two Flow-Flexer pneumatically actuated devices, one of which employs a pair of rams that presses opposing sides of the bag in increasing strokes as the bag decreases in width, and another that uses specially contoured plates that increasingly raise opposing bottom sides of the bag into a steep "V" shape as the bag lightens, promoting complete discharge. Positioned above the clamp ring is a Power-Cincher pneumatically actuated flow-control valve that cinches the spout concentrically, allowing re-cinching of partially empty bags. Construction is of carbon steel with durable industrial finish, with all material contact surfaces of stainless steel. Booth 1005 — *Flexicon Corp., Bethlehem, Pa.*
www.flexicon.com

A conditioner for bulk-bag materials

Discharging bulk bags containing material that has solidified, hardened or agglomerated can be extremely difficult, dangerous and time-consuming if the proper equipment is not utilized. The conditioning system (photo) features a patented pivoting-conditioning-arm design that eliminates performance and maintenance issues found in opposing compression-plate units, and provides up to 261% more force than others for deeper material penetration, and maximum conditioning results, says the company. Booth 3917 — *Material Transfer & Storage, Allegan, Mich.*
www.materialtransfer.com

This split seal is suited for a wide-variety of applications

The OFS Type-1 fully split seal (photo) is especially suitable for vacuum, low-pressure and abrasive applications. The design tolerates both runout and thermal growth at moderate speeds. The OFS Type-1 places a single, hardened, stainless-steel rotary seal face, spring-loaded against a single, bearing-grade, polymeric stationary seal face. The seal does not require a barrier fluid. A wide selection of materials is available, allowing service in diverse processes. The OFS Type-1 split seal is ideal for top-entry agitators, crystallizers, dryers, pan mixers, blenders, hoppers and similar rotating equipment used in the petrochemical, plastics, metals, minerals and other process industries. The OFS Type-1 seal is used with top-entering and horizontal shafts. The seal has been used with crystallizers operating at cryogenic temperatures, and in an environment with saturated steam under full vacuum and relatively hot conditions. The seal is often used both to keep process materials inside the vessel and also to keep atmospheric oxygen from entering the vessel. Booth 2911 — *MECO Seal, Georgetown, Maine*
www.mecoseal.com

Magnetic separation solutions for gravity applications

Choosing the right magnetic separator for gravity-fed processing systems requires taking into account many different factors about the product being processed and the processing conditions. For instance, does the product have a high moisture content or particle size, such as flours, cake mixes or corn starch? Is the product abrasive or corrosive, or does it tend to bridge or gall? Is there a high ambient temperature or humidity level? All of these factors influence the application and require different methods of handling. This company offers four distinct magnetic-separation solutions for removing fine metal particles from gravity-flow processing streams, including the Drawer-in-Housing, the Large Tube Housing the OX and the RotoDrawer (photos). These gravity feed magnetic separators are designed with features such as larger tubes, Nedox coatings or rotating tubes to address each application. Booth 1304 — *Industrial Magnetics, Inc., Boyne City, Mich.*

www.magnetics.com

A tester for when you really need to know the flow of your powder

The Powder Flow Tester (PFT; photo) delivers quick and easy analysis of powder flow behavior. The PFT is ideal for manufacturers who need to eliminate the downtime and expense of erratic powder discharge from hoppers. Users can perform quality-control checks on incoming materials, characterize new formulations for flowability and adjust composition to match the flow behavior of established products. The instrument also offers a solution for small powder samples, which is perfect for pharmaceutical formulators who test expensive powders in limited quantities. The Small Volume Shear Cell requires only 43 mL of powder. Other good candidates include materials that are difficult or messy to handle, such as powdered inks. The Small Volume Shear Cell has an added technical performance advantage, namely the ability to generate higher consolidation stresses, which simulates conditions in larger bins and silos. The PFT includes the Powder Flow Pro v1.2 Software, which has comparison features that allow the operator to combine, display and compare data from both standard and small shear cell tests in a single graph. This gives users the ability to test and compare how powders will respond in small bins with low consolidating stress and in large bins with high consolidating stress. Another feature of Powder Flow Pro v1.2 is the Normalized Flow Function. As more product is added to a hopper, consolidation stress increases raising the potential for stable bridges or "arching" to occur. The Normalized Flow Function enables the technician to predict this behavior and modify the manufacturing process or hopper design to avoid the problem. Booth 2945 — *Brookfield Ametek, Middleboro, Mass.*

www.brookfieldengineering.com

A new-generation monitor for bucket elevator or conveyor

This company recently released its all-new, fourth-generation Watchdog control unit (photo) for monitoring bucket elevators and conveyors. The Watchdog Super Elite (WDC4) is easy to install and simple to set-up. The system processes signals from up to 15 sensors for belt speed, belt misalignment, continuous bearing temperature, pulley misalignment and plug conditions on bucket elevators or conveyors. When an alarm condition is detected, the system will log the details, sound an alarm and provide shutdown control of the elevator/conveyor and feeding system. A new 3.5-in. color graphic LCD screen displays the entire system status at a glance. The WDC4 model now supports belt-speed monitoring for variable-frequency drives, and belt misalignment inputs for contact, pulse and temperature (brass rub block) sensors. The WDC4 also has jog and acceleration monitoring for detecting any equipment issues during the start-up sequence. All Watchdog sensors are CSA Class II, Division 1 approved. Booth 2549 — *4B Components Ltd., Morton, Ill.*

www.go4b.com

Gerald Ondrey

Industrial Magnetics

Brookfield Ametek

4B Components


LEWA


Stahlhandel Gröditz


SensoTech

AchemAsia 2016 — the 10th International Exhibition and Conference on Chemical Engineering and Biotechnology — will take place May 9–12 at the China National Convention Center (CNCC) in Beijing.

In addition to the exhibition, a number of satellite symposia will be taking place during the week. On May 10 is "Euro-Asian Panel: Strategies for Implementing an Industry 4.0 Approach in China," organized by Dechema e.V. (Frankfurt am Main, Germany; www.dechema.de), the German Society of Chemical Engineering and Biotechnology. Dechema also organized the symposium "New Findings in Process Technology," taking place May 10–11. The Chemical Industry and Engineering Soc. of China (CIESC) has also organized a number of symposia at the show, with topics including: International Forums on Applied Process Intensification, and Advances in Industrial Water Technology; Petrochemical Industry "Internet+" Intelligence Construction Symposium; and the 2016 China Chemical Separation Science and Technology Forum. In addition, Sartorius Stedim Biotech (Göttingen, Germany; www.sartorius.com) will present a workshop on Benefitting from Single-Use Technologies in Biopharmaceutical Production.

What follows is a small sample of some of the products being exhibited at the show.

A variety of pumps will be presented here

At this year's AchemAsia, this company is presenting a cutaway model of the Ecodos diaphragm-metering pump (photo). The cutaway model clearly illustrates the operating principle of the low-pressure pump. The distinguishing feature of the Ecodos is that the diaphragm is mechanically driven, rather than hydraulically driven. Another highlight at the show is the Ecosmart series pump — a metering pump that is said to offer the best price/performance ratio in its class. The Ecosmart meters a wide variety of fluids with high precision. Furthermore, the company is presenting a modular metering pump with a variable eccentric drive element for liquid flow adjustment. Also, a remote pumphead and a G3H triplex diaphragm pump will be shown at AchemaAsia. German Pavilion, Stand 030 — *LEWA GmbH, Leonberg, Germany*
www.lewa.com

Customized sawn blanks from more than 60 steel grades

This company offers a wide range of high-quality stainless steels, high-temperature and heat-treatable steels, cementation and nitriding steels, tool steels, structural and constructional as well as special steels. The company has a certified sawing center according to DIN EN ISO 9001: 2008 LRQA, and offers various customized sawn flat and round steel of the highest quality. On request, it can also supply finished machined dimensions. The processing of round steel (photo) is possible up to a maximum diameter of 1,300 mm. The product range also includes open die forgings up to 50-ton piece weight. To give international clients local contact persons, the company founded subsidiaries in Spain, Poland and Thailand, as well as partnerships with representatives in many other countries. The company delivers small and large dimensions and quantities by air- or sea-freight in more than 60 countries on five continents. German Pavilion, Stand P3 — *Stahlhandel Gröditz GmbH, Gröditz,* Germany
www.stahlportal.com

PAT for liquid concentration measurement, and more

In industrial processes, inline process analytical technology (PAT) is used to monitor critical parameters and to control processes for quality assurance, production efficiency and safety. This increases process reliability, reduces costs of raw materials and energy, and eliminates failed productions. The LiquiSonic inline analyzer (photo) measures continuously and precisely the concentration in liquids directly in vessels, tanks and pipes without needing a bypass. Applications include, for example, the production of chemicals and pharmaceuticals, chlor-alkali electrolysis, gas scrubbers, phase separations, alky-

lations, crystallizations or polymerizations. The sensors can be integrated into any plant system and various sizes of pipes and vessels. For automated process control, the measuring results can be transferred to the process control system via 4–20-mA signal, digital outputs, serial interfaces, fieldbus (Profibus DP, Modbus) or Ethernet. With the integrated PC-interface, it is possible to read all data and to create process reports and protocols. Stand M20 — *SensoTech GmbH, Magdeburg–Barleben, Germany*
www.sensotech.com

Accurate dosing of small mass flowrates

Cori-Fill (photo) is a compact solution for fluid dosage, based around the extremely accurate mass measurement of the company's (mini) Cori-Flow series of Coriolis-type instruments, for flowrates between 100 mg/h and 600 kg/h. Cori-Fill technology features integrated batch counters and the facility to directly control a close-coupled shut-off valve for brief batch sequences down to <0.3 s, a proportional valve for longer sequences, or a liquid pump for dosing without the need for pressurized vessels. Cori-Fill offers all this functionality, with plug-and-play simplicity. In contrast to gravimetric processes using weighing scales, where compounds are dosed one by one, Coro-Fill systems can add all ingredients simultaneously, shortening batch and agitation cycles, as well as improving quality. The amount to be dosed can be easily preset by programming the batch counters via a fieldbus connection, with all the standard digital protocols available. Stand F12 — *Bronkhorst High-Tech B.V., Ruurlo, the Netherlands*
www.bronkhorst.com

Welded tubes in a variety of materials and sizes

This company produces welded tubes in stainless steel, duplex, superduplex, exotic alloys and titanium. The production range covers welded tubes, with diameters from 7.24 to 63.5 mm and wall thickness from 0.4 to 4.00 mm. The company is highly specialized in the production of tubes for heat transfer and its main rule is the safeguarding of quality production. To this end a fully controlled working process that requires the respect of very strict parameters has been implemented. In line with this philosophy, the company has achieved ISO9001-2009, AD2000 W0, Lloyd's, Rina, Gost certification, as well as ISO 14001 and BS OHSAS 18001. The manufacturer is currently supplying its tubes to 53 different countries around the world. Stand F35 — *A.D. Tube Inossidabili S.p.A., Casnate con Bernate, Italy*
www.adtubi.com

Gasket tape for sealing glass-lined steel equipment

De Dietrich Process Systems (Munich, Germany; Stand K19), a leading international manufacturer of glass-lined steel equipment, has endorsed and will provide sales, technical and installation support for this company's GORE Gasket Tape Series 1000 (photo), a new sealant product. GORE Gasket Tape Series 1000 was developed to more effectively meet the sealing challenges of glass-lined steel equipment utilizing aggressive media under demanding process conditions, such as high temperatures, alternating system pressures, limited gasket loads and deviation of sealing surfaces. The new tape product incorporates a unique barrier core, which enables it to maintain an extra-tight seal across the full width of the flange — even at low loads, and even in the presence of highly permeating media. Tests demonstrate that Series 1000 produces a seal that is more than ten times tighter than other ePTFE gaskets, with even greater advantage over envelopes when flange deviation is present, says the company. Manufactured in the form of a highly-conformable spooled tape, Series 1000 is optimized for use in large (≥DN 600/ASME 24 in.) or non-standard flanges typically found in columns, mixer vessels, reactors, storage and receiver tanks. With Series 1000, gaskets can be customized on-site, as needed. This eliminates the need for offsite fabrication of large gaskets, and the associated long lead times and complicated logistics for shipping, handling and installation. With Series 1000, gasket inventories can be streamlined, and inventory costs re-

Bronkhorst High-Tech B.V.

W. L. Gore & Associates

Heinkel Drying and Separation Group

Flux-Geräte

Hermetic-Pumpen

duced, says the company. Stand J20 — *W. L. Gore & Associates GmbH, Putzbrunn, Germany*
www.gore.com

A variety of thermal processing equipment is shown here

This company is presenting its extensive product portfolio, which covers centrifuges, dryers, agitated nutsche filters, filter dryers, mixers, agitators and system components for the (fine) chemical, pharmaceutical and food industries. The group, with its brands Bolz-Summix, Comber, Heinkel and Jongia, enables effective process engineering solutions — from laboratory devices to complex production facilities. One of the exhibits at AchemAsia will be a model of the Heinkel inverting filter centrifuge (photo), which finds its use where difficult-to-filter, high-quality, physiologically active or explosive substances are intensively washed and separated from liquids. The inverting filter centrifuge guarantees a heel-free discharge, which allows a fully automatic batch process at constant product quality. Thanks to the centrifuge's completely sealed process chamber, high safety standards are guaranteed. Stand M36 — *Heinkel Drying and Separation Group, Besigheim, Germany*
www.heinkel.de

This drum-emptying system is available as an Ex version

The Ex version of ViscoFlux lite (photo) opens new opportunities across a diverse range of industries, such as chemicals or surface finishing technology. For example, it is suitable for supplying machinery and fast-running equipment with lubricating greases in Zone 1. Alternatively it can be used for pumping Zone 0/1 flammable media, such as various base materials for paints and lacquer manufacturing, as well as numerous coatings and fillers. The individual components of the Ex version (Ex-marking II 1 G IIB TX) — the pump centering plate and follower plate, including process seal, as well as the compressed-air hose — are made of conductive or static dissipative materials. Comprehensive and precise potential equalization can be carried out over suitable connections for grounding wires. Residual volume in the drum is less than 1%. To continuously and gently transport higher-viscosity materials that are just capable of flowing, the company uses eccentric worm-drive pumps. In combination with a follower plate, a vacuum is created during pumping, causing the follower plate to lower. In doing so, the process seal of the follower plate hermetically seals the remaining material, thus preventing unwanted emissions and changes to the product. Stand N12 — *Flux-Geräte GmbH, Maulbronn, Germany;* and *Shanghai Dahui Engineering Co.,a subsidiary of Winston Engineering Corp. (PTE) Ltd.,*
www.flux-pumpen.de
www.winstonchina.com.cn

Canned-motor pump technology has multiple advantages

Canned-motor pump technology (photo) provides significant advantages and often constitutes a low-priced alternative to conventionally sealed pumps and magnetically coupled installations with external drive, since there are no long shafts or complex cooling and lubrication systems of mechanical seals. In conventionally sealed submersible pumps (that is, those equipped with mechanical seals), and also in magnetically coupled in-tank pumps, the motor is installed at the outside of the vessel. Depending on the immersion depth of the pump, this results in a correspondingly long shaft to connect the pump hydraulics to the drive motor. This kind of shaft is fixed, for example, using fluid-lubricated slide bearings, which are typically installed at distances of approximately 1.2–1.6 m. Statistically speaking, however, the probability of failures increases with each bearing. The installation of a submersible canned-motor pump provides a cost-efficient and reliable alternative. Thanks to the hermetically sealed design of the drive unit, which consists of the hydraulic and the motor, it can be completely immersed in the tank. Only the discharge pipe and the electrical connection are routed through the tank cover via the manhole plate out of the vessel. This company's canned-motor pump also provides a monitoring concept that monitors the safe operation of the pump via in-

stalled sensors. In addition to operating temperature, liquid level and motor load, the specially developed MAP system can be integrated. It continuously monitors the position of the rotor and is therefore a reliable indicator for unintended operating states and wear. — Stand N21 — *Hermetic-Pumpen GmbH, Gundelfingen, Germany*
www.hermetic-pumpen.com

Metal alloys for meeting today's trends in Asia

According to this company, two trends were obsreved in the Asian market over the past years. One trend is the increase of efficiency in industrial production. This has led to higher operating temperatures and pressures that can only be safely managed through the use of high-alloyed materials. The second trend is the increasing importance of environmental protection. When burning black and brown coal in power plants, for example, chlorides and other compounds are released, which lead to the formation of contaminated sulfur oxides. To minimize sulfur dioxide emissions, the gases can be cleaned in fluegas desulfurization (FGD) plants, frequently in a wet scrub, with a limestone suspension or seawater. This company's comprehensive portfolio of alloys (photo) — including VDM Alloy 31 Plus, VDM Alloy 2120 MoN, VDM Alloy 59 or VDM Alloy 625 — supports optimum solutions for the challenging tasks of the following applications: petroleum refining, production of phosphoric and superphosphoric acids, phosphate fertilizer, contact with oxidizing and reducing media, sulfuric acid, nitric acid, acetic acid, chlorine, caustic soda, salt production, vinyl chloride monomer production for plastics, synthesis of organic compounds or production of paper and pulp. Stand O36 — *VDM Metals GmbH, Werdohl, Germany*
www.vdm-metals.com

Thermal processing technology for the CPI

This technology and engineering company provides evaporation and crystallization technologies to the fertilizer, chemicals, chlor-alkali and other industries. The company has extensive experience in regeneration of acids, and unique expertise in evaporation and crystallization — from concept to complete plant design. Among its technologies that have application in the fertilizer industry are: phosphoric acid concentration (PAC), phosphoric acid purification (PAP), and evaporation for various acids, bases and other organic and inorganic process liquors; and crystallization for various inorganic salts. Stand N19 — *KBR Ecoplanning Oy, Pori, Finland*
www.ecoplanning.fi

'A perfect fit' for your sealing needs

As one of the leaders of sealing technologies (photo), this company offers optimal solutions with a perfect fit for challenging sealing requirements. The company boasts a sound understanding of sealing problems, extensive know-how in application engineering, and provides consistent manufacturing of reliable, high-quality products. In addition, through user-driven innovation, the company's research and development team is qualified to successfully design the adequate sealing solution via complete production chain and international presence, quality assurance, application engineering, and technical training courses and seminars. Stand L22 — *Donit Tensit d.o.o., Medvode, Slovenia*
www.donit.eu

Simultaneously monitor grounding for multiple equipments

The Earth-Rite Multipoint II Static Grounding System (photo) can monitor the simultaneous grounding of up to eight individual pieces of equipment at risk of discharging electrostatic sparks. The system consists of a hazardous-area monitoring unit that contains eight pairs of red and green LED indicators that verify when the equipment at risk of static accumulation has a resistance of 10 ohms or less to the plant's designated true earth grounding point. The system is an ATEX / IECEx / cCSAus certified system, which identifies ground resistance levels outlined in codes of practice including IEC 60079-31-1 and NFPA 77. Stand N11 — *Newson Gale Ltd., Nottingham, U.K.*
www.newson-gale.com

Gerald Ondrey

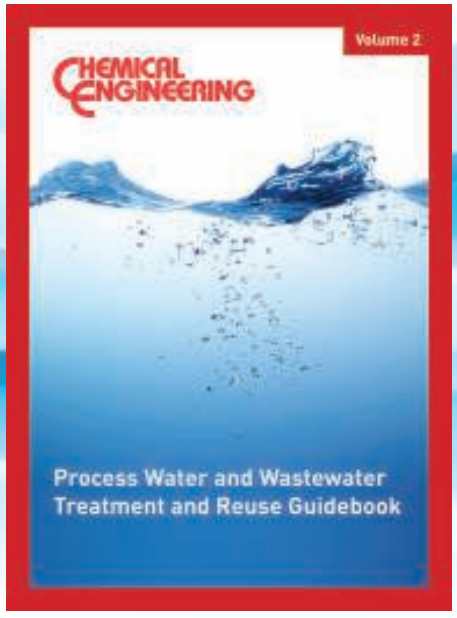
VDM Metals

Donit Tensit

Newson Gale

Now Available in the *Chemical Engineering* Store:

Process Water and Wastewater Treatment and Reuse Guidebook- Volume 2



This guidebook contains how-to engineering articles formerly published in *Chemical Engineering*. The articles in Volume 2 provide practical engineering recommendations for process operators faced with the challenge of treating inlet water for process use, and treating industrial wastewater to make it suitable for discharge or reuse.

There is a focus on the importance of closed-loop or zero-discharge plant design, as well as the selection, operation and maintenance of membrane-based treatment systems; treating water for use in recirculated-water cooling systems; managing water treatment to ensure trouble-free steam service; designing stripping columns for water treatment; and more.

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- Designing Steam Stripping Columns for Wastewater

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SOLIDS Processing

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Access Intelligence

special advertising section

Solids processing

Our special section celebrates the diversity of the market for handling bulk solids

With solids handling and processing playing key roles in the manufacture of almost every product within the chemical process industries (CPI), the diversity of the products and services celebrated in this special advertising section should come as no surprise. The following pages carry expert advice on unit operations including milling, mixing, powder dispersion, drying, and pastillation. There are modular pipework systems, valves for the safe transfer of toxic substances, samplers, and packaging machines. There is advice on explosion safety, and expertise in handling difficult materials. You are sure to find something useful. ■

Inside:

The future of milling is now

The new FreDrive-Lab, which is patented worldwide, is the latest offering from milling specialist **Frewitt** to R&D and analytical laboratories in the fields of pharmaceuticals, food, cosmetics and fine chemicals. This new system brings unmatched flexibility, the company says: with a single Tri-Clamp connection, FreDrive-Lab can convert quickly between five different milling technologies. It also offers the ability to scale up easily to the company's larger FreDrive-Production model whenever the time is right.

The five milling heads comprise a conical sieve mill, cylindrical sieve mill, oscillating mill, hammer mill and pin mill.

Five different milling heads give the FreDrive-Lab the ultimate in flexibility

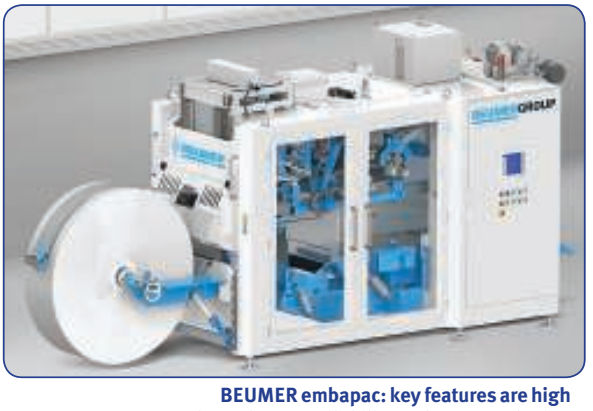
Having all of these integrated into a single piece of equipment makes the FreDrive-Lab extremely cost-effective as well as a superb size reduction tool.

Last but not least, a compact footprint and simple electrical connection facilitates integration within any existing laboratory.

Interphex Booth 2033
POWTECH Hall 1 Booth 343
www.frewitt.ch

Forming, filling, sealing – with outstanding efficiency

The BEUMER embapac is a highly efficient FFS system designed specifically for chemical products, with an emphasis on reliability, ease of use, and energy efficiency



BEUMER embapac: key features are high throughput, availability and compact design

Chemical and petrochemical bulk solids such as plastic pellets may be characterized by high product temperatures, dimensional instability and special flow characteristics. As a result, these materials can be difficult to fill into bags. To meet this challenge **BEUMER** has partnered with chemical companies to develop a new form-fill-seal (FFS) system known as the BEUMER embapac.

The BEUMER embapac forms bags from prefabricated tubular PE film and fills them with materials such as PE, PP, PA or PS pellets, salts, building materials, fertilizers and food products. The system operates reliably, gently and sustainably with bag weights up to 25 kg and throughputs up to 2,600 bags per hour. A built-in weighing unit prevents both under- and over-filling.

With many plants operating 24/7, stoppages are costly. BEUMER therefore sets great store by high availability. The robust design of the embapac extends maintenance intervals, while its modular structure enables easy cleaning. It can quickly be retrofitted to existing packaging lines.

Like all BEUMER machines and systems, the embapac is characterized by energy-efficient, environmentally friendly and safe operation. It is equipped with an ergonomic control terminal with an optimized user interface for easy and intuitive operation.

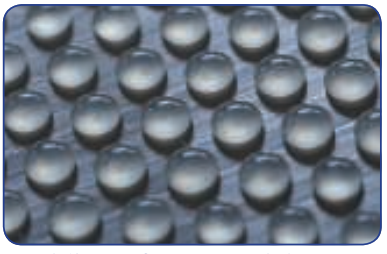
This new system extends BEUMER's product portfolio further along the customers' logistics value chain. Users thus benefit from a single contact for the entire packaging system, from project planning and project management through to service.

BEUMER Group is an international leader in intralogistics technology for conveying, loading, palletizing, packaging, sortation and distribution. Together with Crisplant a/s and Enexco Teknologies India Limited, BEUMER Group employed some 4,000 people in 2014. The group generates an annual turnover of approximately 680 million euros. **www.beumergroup.com.**

Innovation in solidifying melts

Sandvik tackles subcooling melts and high viscosities

Sandvik's Rotoform system is used to convert chemical melts into free flowing, uniform pastilles for easy storage, transportation, dosing and mixing. Applications include the high-productivity solidification



Sandvik's Rotoform 4G SC and Thermocut systems deliver perfect pastilles

of products as varied as resins, hot melts, waxes, fatty chemicals, antioxidants and fine chemicals.

A specialized model, the Rotoform 4G SC, has been developed to handle subcooling melts, which remain liquid even when cooled below their melting points. The reason they refuse to solidify is the lack of crystal nuclei. Sandvik's system overcomes this by introducing a homogeneous suspension of crystal nuclei into the melt. This enables the melt to be crystallized in the desired product form, such as pastilles, micropastilles or flakes. Typical applications for the Rotoform 4G SC include agrochemicals, photochemicals, plastics additives, rubber chemicals, and stabilizers.

The company has also recently introduced its ThermoCut system, an innovative tool that works in conjunction with the Rotoform to deliver perfectly formed pastilles from high-viscosity products.

One of the challenges associated with this kind of product is the formation of threads – commonly known as "angel hair" – when the melt is deposited on the steel belt cooler. The Sandvik ThermoCut system overcomes this to deliver a significantly better-quality end product, while also reducing cleaning requirements.

The system works by blasting a narrow jet of high-pressure heated air at the precise point where the drops form between the Rotoform and the steel belt. This powerful blade of hot air cuts the threads before they have chance to develop further.

www.processsystems.sandvik.com

Maximizing yield in solids blenders

Mixing performance is not the only criterion when choosing a mixer or dryer, says EKATO; emptying is important too

Impellers for powder blenders and dryers are selected primarily for their mixing performance. With expensive products, however, the maximum yield during discharge becomes important too, notes Eberhard Tritschler, Project Manager Sales with mixing specialist **EKATO**.

The EKATO ISOPAS is an impeller created specifically for mixing free-flowing pharmaceutical powders with maximum yield. Its hydrofoil shape is designed both to create efficient flow in bulk solids and to support the outflow.

A typical application example is a pharmaceutical powder that needs to be mixed and discharged with almost no residue. The EKATO VPM vertical solids blender, which is fitted with the EKATO ISOPAS impeller, not only gives rapid blending compared with a helix-type impeller but also shows improved discharge behavior, due to its unique shape with steeply angled blades. As a result, the EKATO ISOPAS impeller is the first choice when both short batch times and minimum residues are required in blending bulk solids.

POWTECH Hall 2 Booth 346
www.ekato.de

Compared to a conventional helical impeller (left), the EKATO ISOPAS (right) gives both faster blending and more-complete discharge

The advantages of thin-film drying

Indirect drying brings high energy efficiency and simplifies the process flowsheet, says Buss-SMS-Canzler

For drying sludges, pastes, filter cakes and wet powders, as well as for heating, cooling and melting, thin-film processes can in many cases be considered the technology of choice, notes **Buss-SMS-Canzler**. Rotor elements convey the material to be dried steadily along the heated wall of the thin-film dryer. Contact with the indirectly heated wall allows optimum heat transfer, whether the process takes place at atmospheric pressure or under vacuum. Thanks to the fully enclosed design, carcinogenic or toxic products can be dried safely.

Indirect drying works well for many sludges and pasty materials

Compared to convection drying, thin-film drying also has the following advantages:

- higher energy efficiency;
- no costly exhaust gas processing; and
- less space is required.

To determine the critical process parameters for contact drying, laboratory or pilot plant trials are recommended. One of these critical parameters is the maximum allowable temperature at the contact surface, which depends, amongst other things, on the thermal stability of the product to be dried. Another important parameter is the tendency to incrustation. Trials also give the opportunity to determine the various product phases that occur during the contact drying process. On the basis of trials, thin-film dryers can thus be safely scaled up for new applications.

www.sms-vt.com

Perfecting particle size for agricultural chemicals

The Micronizer jet mill from Sturtevant boosts reactivity by grinding particulate materials to sub-micron sizes – without the heat buildup that can harm sensitive products

The Sturtevant Micronizer jet mill (photo) yields particle sizes down to 0.25 µm. Its use of fluid energy allows it to out-perform mechanical grinding systems without creating undesirable temperature rise.

Many chemical compounds are highly susceptible to temperature-related degradation. The **Sturtevant** Micronizer brand jet mill reduces the particle size of pesticides, herbicides, fungicides, insecticides, and other dry chemicals to 0.25 µm or larger with narrow size distributions and without heat buildup.

The Micronizer employs high-pressure compressed air, steam or other gas to disperse and deagglomerate the particles. It consistently produces nano-sized particles whose combined surface area is far greater than that of larger particles, which increases their chemical reactivity.

The Micronizer utilizes a unique fluid energy grinding system to generate particle-on-particle impact without raising the product temperature. Activated by high-pressure air, the particles are accelerated into a high-speed rotation in a shallow grinding chamber. As the particles impact on one another their size is reduced. Centrifugal force holds larger particles in the grinding rotation area until they have achieved the desired fine particle size. Centripetal force drags the desired particles towards the static classifier where they are allowed to exit upon achieving the correct particle size. The final particle size is controlled by varying the rate of the feed and propellant pressure. The high-performance design surpasses the economical fineness limit of many mechanical grinders.

The Micronizer's open manifold design allows complete access to the grinding chamber and compressed air chamber for easy cleaning, product changeover, or inspection. There are no dead zones to trap material, no moving parts to wear, and no grinding media or lubricants to contaminate the material being milled.

Sturtevant can solve the most challenging wear and contamination problems using interchangeable wear-resistant liners such as Pureline, ShieldOx, and ArmorLine, and specially engineered coatings like Lubriguard, to provide contamination-free wear protection and enhance the performance of agricultural chemicals.

The Micronizer can also be found in sanitary applications such as pharmaceuticals, nutraceuticals, food ingredients, and biotechnology, as well as metals, pigments, coatings and cosmetics.

Sturtevant offers a fully equipped test facility for conducting customer trials to determine the optimum equipment and system layout for each application.

www.micronizer.com

Ultra-high speed powder dispersion made simple

Ross SLIM Technology employs high shear for rapid and complete mixing of powders into liquids, avoiding agglomerates and dust formation

The **Ross** Solids/Liquid Injection Manifold (SLIM) is a technology for dispersing challenging powders like fumed silica, gums, thickeners and pigments using a specially modified high shear rotor/stator generator.

In both batch and inline designs, the SLIM is easy to retrofit into almost any process. In an inline set-up, the SLIM mixer pumps liquid from the recirculation tank while simultaneously drawing powders from a hopper. As the liquid stream enters the rotor/stator assembly, it immediately encounters the powder injection at the high shear zone. The mixture is then expelled through the stator at high velocity and recirculated back into the tank. In just a few short turnovers, solids are completely dissolved or reduced to the desired particle size.

This method for high-speed powder injection is ideal for dispersing small concentrations of hard-to-wet solids like CMC or xanthan gum (>5%). It is equally effective for solid loadings as high as 70%, as in the case of titanium dioxide or magnesium hydroxide slurries. By introducing solids sub-surface where they are instantly subjected to vigorous agitation, issues like floating powders, excessive dusting and formation of stubborn agglomerates ("fish eyes") are eliminated. Because the SLIM generates its own vacuum for powder induction and does not rely on external eductors or pumps, it is free of clogging and simple to operate.

Several models are available including automated skid packages where the SLIM mixer is piped to a jacketed tank and supplied with flowmeters, load cells, solenoid valves, level sensors and thermocouples all integrated into a PLC Recipe Control Panel. Each ingredient addition and process step can be pre-programmed so that mixer speed, mixing time, temperature, composition and batch weight are accurately replicated in every run.

Ross Inline SLIM powder induction mixer with built-in control panel mounted on a portable cart with work bench

Established in 1842, Ross is one of the world's oldest and largest manufacturers of process equipment, specializing in mixing, blending, drying and dispersion.

www.highshearmixers.com

Handle virtually any bulk solid material

Flexicon stand-alone equipment and automated plant-wide systems convey, discharge, condition, fill, dump and weigh batch bulk materials dust-free

Flexicon engineers and manufactures a broad range of equipment that handles virtually any bulk material, from large pellets to sub-micron powders, including free-flowing and non-free-flowing products that pack, cake, plug, smear, fluidize, or separate.

Individual bulk handling equipment includes: flexible screw conveyors, tubular cable conveyors, pneumatic conveying systems, bulk bag dischargers, bulk bag conditioners, bulk bag fillers, bag dump stations, drum/box/container dumpers, and weigh batching/blending systems. Each of these product groups encompasses a broad range of models that can be custom engineered for specialized applications, and integrated with new or existing upstream and downstream processes and storage vessels.

All equipment is available to food, dairy, pharmaceutical and industrial standards.

For large-scale bulk handling projects, Flexicon's separate Project Engineering Division provides dedicated Project Managers and engineering teams on four continents to handle projects from concept to completion. Working with each customer's preferred engineering firm or directly with their in-house team, Flexicon adheres strictly to the customer's unique standards, documentation requirements and timelines through a single point of contact, eliminating the risk of coordinating multiple suppliers.

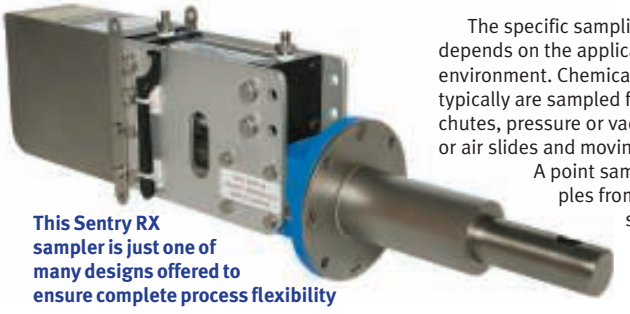
Flexicon's worldwide testing facilities simulate full-size customer equipment and systems, verify performance prior to fabrication, demonstrate newly constructed equipment for visiting customers, and study the performance of new designs.

Flexicon offers stand-alone bulk handling equipment as well as plant-wide systems integrated with new or existing processes

In 2015 the company doubled the size of its manufacturing facility and world headquarters in Bethlehem, PA, and also operates manufacturing facilities in Kent, United Kingdom; QLD, Australia; and Port Elizabeth, South Africa. **www.flexicon.com**

Reliable sampling solutions for solids

Sentry Equipment Corp. carefully designs and customizes a range of solid and powder samplers for specific applications



This Sentry RX sampler is just one of many designs offered to ensure complete process flexibility

Representative sampling and analysis in the chemical industry can be required wherever solid materials are handled, says **Sentry Equipment Corp.** – from validating raw material, identifying process variations and ensuring product quality, to by-product environmental compliance and custody transfer. With representative sampling, characteristics of each sample match that of the entire lot or batch – so samples are repeatable and companies can be confident that analysis data is accurate.

The specific sampling technique chosen depends on the application and the process environment. Chemical solids and powders typically are sampled from hoppers or drop chutes, pressure or vacuum conveyor lines, or air slides and moving conveyor belts.

A point sampler captures samples from a point in a process stream, and often is used when the material is homogenous. A strip sampler captures a sample strip across the diameter of a process stream, so it is used in situations where product segregation exists. A crosscut sampler, which captures a cross-section of an entire product stream, requires adequate headroom above it to operate.

Two applications in which Sentry Equipment worked with customers in the chemical industry illustrate how differing applications require different sampler configurations and modifications. One customer needed to take samples of chemical waste fly ash from four pneumatic conveyor lines, mounted vertically with upward flow. As fly ash is free-flowing, dry and abrasive, stainless steel containers were needed. The Sentry PR automatic point sampler was the best solution for this application, since it can handle the pressure of a pneumatic conveying line, is suitable for abrasive powder, and can be mounted vertically.

Another customer needed to sample a catalyst discharging from a dryer. Because the material took the form of cylinders up to 0.5 in. (12 mm) in diameter, an oversized sampler was required. However, the available headroom, from the dryer discharge to the inlet of a bucket elevator, was less than 4 ft. (1.2 m). The best solution for this application was an oversized Sentry RX automatic strip sampler with a 3-in. (75-mm) diameter sample tube, designed with a custom pre-mount section with square flanged ends to match the customer's angled chute. This shows how Sentry samplers can be designed to meet any application, anywhere.

sentry-equip.com/chemical

Hazardous area installations cover the complete range

Pepperl+Fuchs describes how to specify the most efficient protected solutions for hazardous areas, from a simple emergency stop to a complex control system

Safety in hazardous areas is a complex subject controlled by a multitude of international, regional and company-level regulations and standards. To find the most efficient control solution for a given application, **Pepperl+Fuchs** offers a comprehensive portfolio via its Solution Engineering Centers (SECs) located around the world.

Various types of protection are set out in the international standard on explosion protection, IEC 60079, and recognized by regulations such as Europe's ATEX 95 Directive. For plant control, "intrinsic safety" (Ex i) is popular as it allows work on live circuits. Most modern remote I/O and fieldbus systems use Ex i, but the power available to connected devices is very limited. "Increased safety" (Ex e) provides more energy, but requires equipment to be shut down for maintenance. Other classifications such as "flameproof" (Ex d) and "pressurized" (Ex p) cover the use of standard electrical equipment in specially designed enclosures.

The trick now is how to find the most efficient explosion protection method for the specific application, also taking into account dusty or corrosive atmospheres, extreme temperatures, and requirements for hygiene. As a leader in explosion protection and plant automation, Pepperl+Fuchs offers products and solutions covering all types of protection as well as highly qualified consultancy and project management.

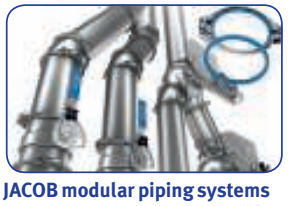
From first evaluation to final specification and manufacturing, the company's experienced project engineers design the most appropriate explosion protected solution in cooperation with the user. The result could be an interface cabinet equipped with various IS barriers from the comprehensive Ex i portfolio, a remote I/O field unit complete with all components and accessories, a fieldbus junction box combining FieldBarriers, fieldbus process interfaces and solenoid valves, or an integrated fire and gas detection, safely protected in a flameproof or pressurized enclosure.

Every solution is assembled by trained specialists in one of the company's ISO 9000-certified SECs. Continuous quality control and functional tests guarantee perfect operation. **www.pepperl-fuchs.com**

MAC003125 pressurized enclosure for IS barriers and HMI, with purge controller mounted on the outside

No.1 for modular pipework

JACOB claims to be Europe's leader in modular pipework. Conveying pipe systems for bulk goods handling and dust extraction are the two main scopes for JACOB pipe systems. These are not custom-built with welded flanges, which is both costly and time consuming. Instead they are designed as flexible modular systems that allow quick and low-cost assembly. Modularity enables easy cleaning as well as the ability to extend or modify existing piping systems at any time.



JACOB modular piping systems are easy to install and modify

With subsidiaries in Europe and North America, as well as over 40 representatives worldwide, the JACOB GROUP is as global as its customers.

The company's headquarters are located west of Hanover in the town of Porta Westfalica, Germany. Here is the largest production plant within the group, employing around 500 staff. State-of-the-art press forming and laser manufacturing allow mass production with tools developed in-house, as well as custom constructions. JACOB offers the most comprehensive modular pipework system available, with more than 7000 items, housed in Europe's largest warehouse of its kind, with more than 1,000,000 products stocked. Four production locations enable rapid and reliable deliveries. For foodstuffs, the stainless steel meets EC 1935/2004 and FDA standards.

POWTECH Hall 4 Booth 431
www.jacob-pipesystems.com

Dryer simplifies scale-up

Wyssmont Co. is exhibiting its test model H-10 TURBO-DRYER at the forthcoming International Powder & Bulk Solids Conference and Exhibition, Rosemont, Ill., May 3–5. Test results from this unit are directly scalable to larger capacities. The new lab-scale dryer is designed for easy cleaning between products and is used to dry water-wet or solvent-wet materials, with solvent recovery and without the need for vacuum.

Wyssmont's new lab-size dryer simplifies the design of production-scale dryers

The benefits of the full-size TURBO-DRYER models include the ability to dry to extremely low moisture, gentle handling for fragile materials with negligible particle breakage and very low dust carryover, automatic operation, unparalleled product uniformity, and low horsepower and heat requirements.

The TURBO-DRYER principle is based on a stack of slowly rotating circular trays; wet material enters at the top and falls to the tray below after one revolution. Diameters of production-scale dryers range up to 35 ft.

www.wyssmont.com
International Powder & Bulk Solids Conference and Exhibition: Booth 1000

Solutions for any bulk materials handling problem

For 50 years Jenike and Johanson has been using its expert knowledge to prevent and solve problems in bulk solids handling

Jenike & Johanson, Inc. is the world's leading technology company for bulk material handling, processing, and storage. The company delivers engineered solutions to achieve reliable powder and bulk solids flow based on proven theories and decades of project experience. With its skilled, highly technical team of experts and industry-leading innovations, Jenike & Johanson has successfully delivered bulk material engineering solutions for more than 55 years.

Bulk materials and their flow properties are at the core of all Jenike & Johanson's work. Every project (over 7,500 to date) is truly unique. The company rejects the "one size fits all" concept, so clients have maximum flexibility in selecting services to meet their bulk material handling needs.

That is important because if bulk solids systems are not engineered from the outset to handle the unique characteristics of the materials concerned, process start-up can be significantly delayed and design capacity may never be reached. When feeding powders to reactors or conveying wet cake from a centrifuge to a dryer, for instance, poor material flow can result in throughput limitations, non-uniform product, or dust emissions and spillage. Reliable solids handling improves unit operations involving blending, extrusion, pneumatic or mechanical conveying, and heating or cooling. Reliable powder flow and a first-in, first-out vessel discharge pattern (mass flow) is desired to minimize cross-contamination of batches and ensure process efficiency.

The key to preventing or solving solids handling problems lies in knowing their causes. The engineers at Jenike & Johanson are renowned experts in bulk material engineering, and they offer an expansive range of services to support projects in the chemical industry:

- on-site audit to review the process or the flow problem;
- flow testing of materials in raw, intermediate, and final grades;
- design of storage vessels, chutes, and feeders;
- tests for pneumatic conveying;

Jenike & Johanson's success is founded on the expertise of its engineering team

- silo structural engineering (both new and retrofit); and
- pilot-scale process modeling.

Whether conveying raw materials from storage silos to a process, feeding powders to a reactor, or packaging products in bulk, Jenike & Johanson can help to achieve reliable material flow and high throughput.

www.jenike.com

Transfer toxic substances

Whether operated manually or automatically, the MCV Müller Containment Valve from

Now even safer: the new MCV Müller Containment Valve

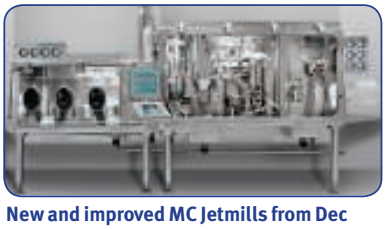
Müller ensures safe product transfer from an intermediate bulk container into the process line and back again. After successfully launching its own split valve in 2009, Müller optimized the MCV in 2014 to meet even higher requirements. The new generation of MCV is suitable for applications up to OEB Level 5 (SMEPAC), i.e. up to OEL < 1 µg/m^3. In addition to the higher OEB level, the improvements benefits the operators who use the valve. The new design is lightweight, compact and self-locking. The locking mechanism is smooth-running and powerful, with no rollers or bolts – so there is no mechanical wear. Changing over from the manual to the pneumatic version or refitting position sensors is simple and quick.

Several versions of the MCV are available, including ones suitable for working pressures up to 6 bar. Where there is an explosion risk, versions can be supplied to resist explosion pressure shock and flame breakthrough for gases in group IIB up to 10 bar (except valve size DN 250, which is rated up to 6 bar). All valves are made from AISI 316L stainless steel, or Hastelloy as an option. Available sizes are DN 65, DN 100, DN 150, DN 200 and DN 250.

www.mueller-gmbh.com /qr/containment

Advances in micronizing

Dec Group has announced significant improvements to its range of jet mills. The fourth generation of fluid energy mills allows greater manipulation of the particle size distribution (PSD) and the production of nanoparticles below 1 µm, while maintaining complete product scalability throughout the MC Jetmill series. This development focused on dealing with the most difficult products from sticky to hard, while minimizing blow-back phenomena and product buildup through the use of alternate materials and improved internal shapes for the chamber and nozzles. Advanced mathematical modelling has also helped to increasing milling energy at low feed rates. The result is superior yields, significantly improved PSD manipulation, better ergonomics, and less downtime.



New and improved MC Jetmills from Dec

Further advantages include enhanced efficiency with sticky powders and inhaled products that demand even distribution of active drug particles, simplified full CIP and SIP options for aseptic production, and easy assembly without tools.

MC Jetmills can optionally be supplied with isolators to provide full containment of highly active and/or sterile materials as well as optimum operator and product protection.

www.dec-group.net

Control combustible dust and comply with OSHA

SonicAire fans solve overhead fugitive dust problems with proactive engineering designs to provide continuous compliance with safety regulations

SonicAire clean fans have a track record of success in controlling the dangerous buildup of fugitive dust. In fact, says the company, they are the only proven solution that prevents dust from accumulating on overhead structures. SonicAire fans also save money: a one-time investment means a long-term solution for overhead combustible dust.

The newest line is the 2 Series, which contains several compelling options. The flagship SonicAire 2.0 is a powerhouse fan with a 2 HP TEAO motor that delivers twice the cleaning of the original SonicAire fan. This means that installation costs are cut in half, and the SonicAire 2.0 can pay for itself in as little as one year.

The newest fan in the series, the SonicAire 2.xm, offers exceptional performance to meet U.S. NEC requirements for Class 2 Div 2 hazardous locations. This fan boasts key features including:

- explosion-proof motor;
- extended shroud for a balanced fan oscillation assembly; and
- NEMA 12 electrical enclosure.

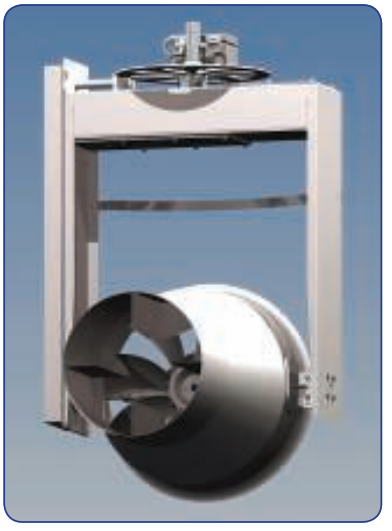
The SonicAire 2 series has other variations that can be added separately, or combined in one fan to suit specific applications:

- SonicAire 2.c: The "c" stands for "compact". This variation can be placed in tight spaces.
- SonicAire 2.hw: The "h" stands for "heat". This fan can work in temperatures up to 180°F (80°C). The "w" stands for "water". This fan is water-tight.

Every SonicAire fan is powered by BarrierAire technology. As its name suggests, BarrierAire creates an air barrier that shields overhead structures from dust buildup. This is achieved through precisely directed air flows with high mass and high velocity. Facilities can thus consistently maintain the high levels of cleanliness they need to comply with OSHA and other regulations on overhead combustible dust.

SonicAire offers a "try and buy" program that lets customers try a fan for 60 days and return it if they are not 100% satisfied.

sonicaire.com



Fans in the SonicAire 2.0 series are targeted at demanding applications such as the chemical and allied industries

Versatile spray dryer series is still going strong

GEA is showing off the latest addition to its MOBILE MINOR spray dryer range among other recent developments at POWTECH

The MM-100 is the newest addition to GEA's proven MOBILE MINOR range of spray dryers

Exhibiting at POWTECH this year, **GEA** will highlight its innovative solutions and manufacturing expertise, showcasing new products and developments for a wide range of industries and applications.

Offering an improved design but maintaining the same compact footprint, the MM-100 spray dryer from GEA is the newest addition to the MOBILE MINOR range.

The design of the MOBILE MINOR spray dryer has been improved many times, but its compact footprint remains the same. This is one of the main reasons for its ongoing success and constant evolution as a pilot plant and/or small production unit. Now, for example, specific versions for the pharmaceutical industry have been developed and GEA has introduced yet another series of new and enhanced designs.

The new MOBILE MINOR MM-100 can operate with a process gas flowrate of up to 100 kg/h at an inlet temperature of 200°C, which for many products means a 30% increase in powder production compared with the current version. High-capacity HEPA filters for baby food or hazardous chemical applications are available, and powder collection glasses in sizes from 250–3500 ml can be supplied as standard.

An accurate hot drying gas flow pattern is key to minimizing powder deposits. Computerized fluid dynamic (CFD) modeling and cutting-edge manufacturing technologies have been used to ensure high levels of precision. The universal gas disperser for the rotary atomizer as well as the two-fluid nozzle can easily be exchanged with an optional low-velocity gas disperser – which has a similar flow pattern to the DPH gas dispersers used in larger PharmaSD spray dryers – for nozzle atomization.

Installed in almost 2,400 plants worldwide, the cross-application MOBILE MINOR spray dryer is robust, reliable and versatile. The MM-100 boasts a powerful supply blower with flow indication, is easy to use and move, and has laser-cut gas guides that are easy to remove and clean (patent pending).

POWTECH Hall 3A Booth 237
www.gea.com

Understand the phases of batch vacuum drying

Appreciating the different modes of heat transfer that characterize vacuum drying helps when choosing the right equipment, explains Jeff Hoffmann of Paul O. Abbe

Vacuum drying of solids provides several advantages including lowering solvent vaporization temperature, protecting the product from excess heat, a fully contained environment, and easier vapor recovery. Vacuum lowers the temperature at which the solvent evaporates. This raises the temperature differential between the heated jacket and the evaporating liquid, and so increases the thermal driving force. For example, at atmospheric pressure water vaporizes at 212°F. At 27 in. Hg of vacuum, water will vaporize at 113°F, which increases the temperature differential by 99°F. As long as there is unbound moisture to freely evaporate, the solids will not exceed 113°F.

Batch vacuum drying of solids goes through three basic phases. During these three phases, the thermal, vapor and drying characteristics will change in predictable ways and can be used to recognize transition and end points.

The first phase of vacuum drying is the **warm-up phase** where the initial heating of the vessel and the product to be dried occurs. During this warm-up phase the system temperature increases in a predictable fashion. The heat input is known as sensible heat because it can be sensed and measured as an increase in temperature.

In the second phase of vacuum drying most heat energy goes to vaporizing the liquid. While unbound or free moisture is being removed, the product temperature cannot exceed the vaporization temperature at the given vacuum level. This phase is also known as the **constant-rate drying phase** because the moisture will come off at a constant rate. The system temperature and the vacuum level remain constant, and all of the additional energy, aside from some heat loss to the surroundings, will be going into the vaporization of the liquid.

The third phase of vacuum drying, known as the **falling-rate drying phase**, begins once all the unbound moisture has been removed, leaving only moisture bound within the product. This moisture must work its way to the surface of the solids by capillary action and diffusion before it can evaporate. With a reduced evaporation rate, there is less evaporative cooling and the product temperature will start to approach the temperature of the jacket. A "critical moisture level" marks the start of the falling-rate phase. Because the vapor load is now low, deeper vacuum can be pulled on the system. **www.pauloabbe.com**

This Rota-Cone dryer from Paul O. Abbe is typical of vacuum drying equipment

Particle sizing

One aspect of bulk solids technology not explicitly mentioned by the vendors in this special advertising section is particle sizing. Accurately measuring particle sizes and size distributions is often essential for quality control of both raw materials and finished products.

The previous issue of this magazine contains a useful article on choosing particle-sizing technology in the *Facts at Your Fingertips* section (*Chem. Eng.*, March 2016, p. 46). The most popular techniques are sieving, laser diffraction, automated imaging, and dynamic light scattering. Less-common methods include electrophoretic light scattering, sedimentation, and electrozone sensing.

Sieving is simple, works with coarse as well as fine powders, and uses inexpensive equipment. Measurements take several minutes, however, and may be variable. **Laser diffraction** is quick, accurate, and suitable for automation, but needs dilute samples, and has limitations with highly non-spherical particles. **Automated imaging** is the most accurate, but is best suited to laboratory use. ■

Uniform pastilles from diverse melts

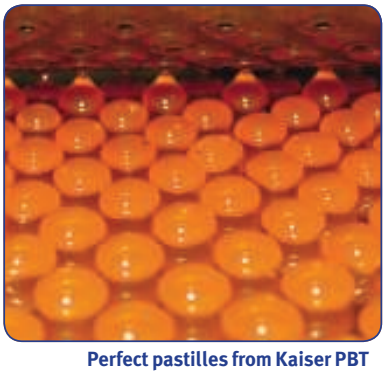
KAISER Process and Belt Technology has seven decades of experience in pastillation all over the world

More than 9,000 test runs, 1,200 units delivered worldwide and 70 years' experience in pastillation, plus being the only company worldwide to offer various pastillation systems, are a few good reasons to choose **KAISER Process and Belt Technology** (PBT) to transform products from melts to solids.

When providing a pastillation system to suit the specific requirements of the customer, experience is crucial. The smallest variation in just one key factor, like the speed of the cooling belt or the temperature of the melt, can lead to completely different results. Kaiser PBT accepts the complex functionality of pastillation systems as a challenge. Experts at the company's laboratory and state-of-the-art test center in Willich, Germany, patiently adjust the settings until they get satisfactory results.

Over seven decades KAISER PBT has gained the experience needed to reach any objective in the complex field of pastillation. That includes both low-viscosity amorphous melts and highly viscous polymers, corrosive products, melts containing solid particles, and products that show supercooling.

As well as pastillation units, KAISER PBT offers a wide range of tailor-made cooling conveyors, including strip granulation units and flaking units with single- or double-belt coolers. The use of two belts minimizes both the system footprint and the time required for cooling. **www.kaiser-pbt.de**



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Schenck Process LLC
www.accuratefeaders.com/mechatronfeeders.html

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Measure energy flow with these smart meters

InnovaMass 240i and 241i vortex mass flowmeters (photo) are specifically designed for precise energy management in steam, compressed-air, natural-gas and water applications. The meters are equipped with the Raptor II operating system, which allows for fast processing and enables the use of robust software applications, including FloPro, which improves point-velocity accuracy. The patented sensor technology extends the measurement range for fluids with Reynolds numbers well below 5,000. The onboard Smart Interface Portal (SIP) software provides quick access to field validation and meter configuration. Users can also access diagnostics through the SIP or the meter's LCD display to automatically check firmware and hardware, and report faults to the factory for immediate repair. Tuning from the SIP or local display allows field adjustments for the low-flow cutoff and vortex coefficient. Through the SIP, firmware can also be updated or repaired in-situ.

Sierra Instruments, Inc. www.sierrainstruments.com

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Setting new standards with the first radar level sensor for liquids with 80 GHz

Measuring at a frequency of 80 GHz allows considerably better focusing of the radar beam, even under difficult conditions, such as tanks fitted with heating coils, baffles or agitators. This means that levels can now be measured in applications where the process or structural conditions were previously not suitable for radar. The new level radar sensor VEGAPULS 64 has a beam angle of only 3°. Until now, a radar sensor with a transmission frequency of 26 GHz and an 80 mm-diameter antenna had a beam angle of approximately 10°. It can be used in vessels with internal installations or heavy build up on the walls, as its focused microwave beam simply avoids these obstacles. The smallest antenna is no bigger than a 1 Euro coin and therefore ideal for wide use in the chemical, pharmaceutical and food industries thanks to its hygienic materials and design.

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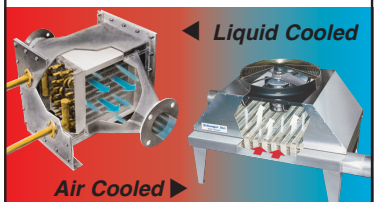

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Economic Indicators

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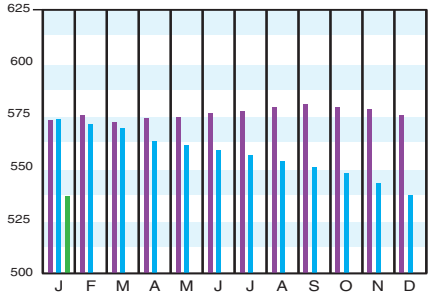
(1957-59 = 100)	Jan. '16 Prelim.	Dec. '15 Final	Jan. '15 Final
CE Index	536.5	537.0	573.1
Equipment	640.5	641.1	694.8
Heat exchangers & tanks	551.7	556.0	636.4
Process machinery	648.5	649.2	663.5
Pipe, valves & fittings	795.0	791.3	868.9
Process instruments	379.0	381.2	407.2
Pumps & compressors	979.1	965.0	948.7
Electrical equipment	509.0	507.7	513.9
Structural supports & misc	701.9	703.0	758.0
Construction labor	320.2	321.6	321.5
Buildings	537.8	536.6	546.9
Engineering & supervision	317.7	316.2	320.1

Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics

Annual Index:
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8



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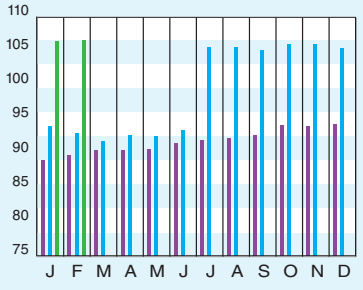
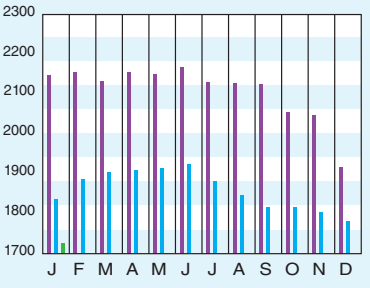
	LATEST		PREVIOUS		YEAR AGO	
CPI output index (2012 = 100)	Feb.'16 =	106.5	Jan.'16 =	106.3	Dec.'15 =	105.9	Feb.'15 =	104.8
CPI value of output, $ billions	Jan.'16 =	1,725.6	Dec.'15 =	1,773.5	Nov.'15 =	1,796.2	Jan.'15 =	1,864.0
CPI operating rate, %	Feb.'16 =	76.5	Jan.'16 =	76.4	Dec.'15 =	76.1	Feb.'15 =	76.0
Producer prices, industrial chemicals (1982 = 100)	Feb.'16 =	221.7	Jan.'16 =	225.0	Dec.'15 =	233.4	Feb.'15 =	242.4
Industrial Production in Manufacturing (2012=100)*	Feb.'16 =	106.4	Jan.'16 =	106.2	Dec.'15 =	105.6	Feb.'15 =	104.5
Hourly earnings index, chemical & allied products (1992 = 100)	Feb.'16 =	157.9	Jan.'16 =	159.9	Dec.'15 =	159.5	Feb.'15 =	157.3
Productivity index, chemicals & allied products (1992 = 100)	Feb.'16 =	109.0	Jan.'16 =	108.7	Dec.'15 =	108.6	Feb.'15 =	107.2

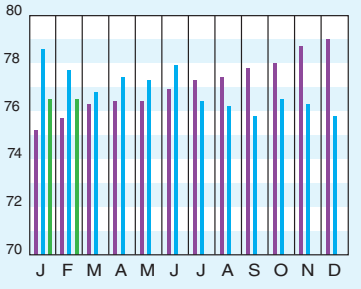
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The annual value for the *CE* Plant Cost Index (CEPCI) was calculated to be 556.8, down significantly from the annual value for 2014. The monthly preliminary value for the January 2016 *CE* Plant Cost Index (top; the most recent available) continued to fall from prior months. While the overall CEPCI value fell from last month, some of the individual subindices rose in January, including pipes, valves and fittings; pumps and compressors; electrical equipment; and buildings. The preliminary CEPCI value for January 2016 is 10.0% lower than the corresponding value from a year ago at the same time. Meanwhile, the latest Current Business Indicators (CBI; middle) for February 2016 showed a slight increase in the CPI output index.

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