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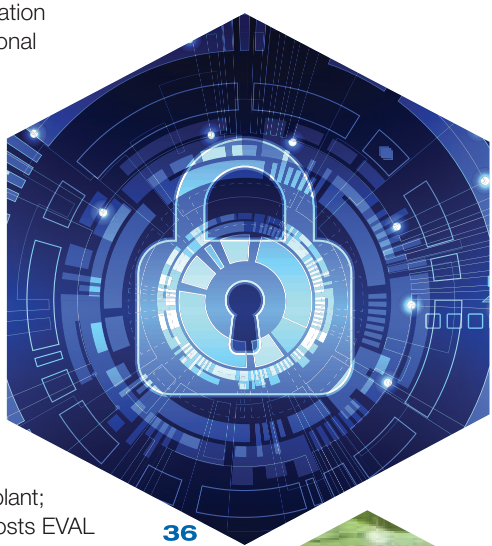
Cover Story

In the News

Technical and Practical



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CHEMICAL ENGINEERING
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Editor's Page

Modernizing TSCA

Last month, the U.S. Congress passed the Frank Lautenberg Chemical Safety for the 21st Century Act. This bill, called "historic" by many, brings very significant changes to the 40-year-old Toxic Substances Control Act (TSCA). This much-needed modernization of TSCA is supported by the chemical process industries (CPI), as well as by environmental and health organizations, such as the Environmental Defense Fund (www.edf.org), the Humane Society of the U.S. (www.humanesociety.org), the Physicians Committee for Responsible Medicine (www.pcrm.org) and others. The bipartisan bill, initiated by the late Senator Frank Lautenberg (D-N.J.) and Senator David Vitter (R-La.) in 2013, has undergone three years of negotiations and revisions, and is, at the time of this writing, now awaiting the expected final approval of the U.S. President to become law.

Reactions by the CPI

Upon passage of the bill, American Chemistry Council (ACC; www.americanchemistry.com) president and CEO Cal Dooley stated "Today's passage of the Frank R. Lautenberg Chemical Safety for the 21st Century Act is truly historic. This legislation is significant not only because it is the first major environmental law passed since 1990, but because TSCA reform will have lasting and meaningful benefits for all American manufacturers, all American families and for our nation's standing as the world's leading innovator."

William Allmond, vice president of Government and Public Relations for the Society of Chemical Manufacturers and Affiliates (SOCMA; www.socma.com) said, "Last night's historic vote is a significant ending and beginning. It ends many years of elusive bipartisan compromise to reform our nation's chemical control law and begins the process of regaining the public's confidence in everyday products made possible by our industry. SOCMA is eager to work with EPA and all stakeholders to ensure that the regulatory process reflects Congress' intent."

And The Dow Chemical Company's (www.dow.com) chairman and CEO, Andrew Liveris, commented, "This landmark legislation will fundamentally reform our nation's chemical regulatory program, restore confidence in the safety of chemicals and provide companies like Dow with the regulatory certainty necessary to drive investment."

What it means

Overall, the new legislation will empower the U.S. Environmental Protection Agency (EPA; www.epa.gov), and also give it more responsibility, for chemical regulation. Some of the main elements of the bill are the following*: All commercial chemicals are subject to an EPA review; EPA is required to focus on high priority chemicals, based on a risk-based prioritization process; Extensive risk evaluations are required on chemicals found to be high priority in a health-based risk evaluation; The quality of science used in EPA decisions must be transparent; EPA's ability to require additional health and safety testing is expanded; EPA is provided with a full range of regulatory options to address chemical risks; EPA is required to meet strict deadlines; Substantiated confidential business information is protected.

While the hurdles of getting long-awaited TSCA reform have been overcome, the hard work of implementing the modernized bill will now begin, and will require the earnest cooperation of all parties. ■

Dorothy Lozowski, Editor in Chief

*Source: U.S. Senate Environment and Public Works Committee, "Reforming the Toxic Substances Control Act" (www.epw.senate.gov/public)

Letters

CARBON STEEL PIPING

At the April 2016 Seattle meeting of the ASME B31.3 Process Piping Code Committee, a presentation — a cautionary note in a manner of speaking — was given by Barry Messer of Fluor Corp. (www.fluor.com). The topic was the unexpectedly low toughness with regard to various carbon steels in the form of pipe, forged flanges and wrought fittings.

Such an innocuous sounding topic is, in actuality, a potentially devastating anomaly that has found its way, under the radar I might add, into the chemical processing and refinery industries. As Messer points out, the suspect material meets all of the ASTM chemical and mechanical requirements, while at the same time undergoes brittle failure under ambient conditions during laboratory testing, hydro-testing, system startup, and while in depressurizing service.

The steel grades of concern are:

- Forgings/Fittings: ASTM/ASME A234 Gr. WPB
- Flanges: ASTM/ASME A105/N
- Pipe: ASTM/ASME A106 and A53, API 5L Gr. B
- All ASME B31.3, Figure 323.2.2A Curve B materials (the materials actually behave like Curve A materials)

Acceptable Steels with Impact Testing at –45°C (–50°F):

- Forgings/Fittings: ASTM/ASME A420 Gr. WPL6
- Flanges: ASTM/ASME A350 Gr.LF2, Cl.1 (Some failures experienced)
- Pipe: ASTM/ASME A333 Gr. 6

The presentation showed that there are two separate mechanisms at play:

- With regard to A105 and A350 LF2 forged flanges, poor forging process and heat treatment techniques have resulted in a coarse grain at the hub and radius of flanges with poor Charpy impacts. Contrary to the failed Charpy tests, testing in accordance with ASTM, performed on coupons from the body area of the flange, provided good results. In other words, the results presented a false positive. This is not a new problem. If the grain is not too coarse, toughness can be recovered through renormalization. Work is underway to fix this in the ASTM standards.
- The second mechanism is a more recent occurrence and concerns a detrimentally low Mn/C ratio (primarily due to cost cutting efforts that are similar to alloy shaving in stainless steels), which increases the temperature transition shift to higher temperatures along with additions of Ti, Nb, V and B that, in turn, seems to increase transgranular susceptibility approximately 45 degrees to the forging or rolling direction. Furthermore, toughness for the second mechanism is not recoverable by additional heat treating.

Until a final resolution is reached at the national standards level, this cautionary note can serve as something of a heads-up in the interim. But while we wait, and until something is published in the appropriate national standards, there are a few precautionary steps that I would suggest, as follows:

1. Unless included in the ASTM material specifications for CS forged fittings, flanges and pipe, request in your company's material specifications impact test-

Letters

ing of the following materials at a minimum design metal temperature, if used, under the following requirements:

Specified Minimum Tensile Strength ksi (MPa)	Average Impact Value for Three Specimen ft-lbf (J)	Minimum Impact Value for One Specimen ft-lbf (J)
65 (448) and lower (for example, A/SA 106, 53, 234 WPB)	13 (18)	10 (14)
>65 (448) to 75 (517) (for example, A/SA 105)	15 (20)	12 (16)
>75 (517) to 95 (656)	20 (27)	15 (20)

2. Or control the Mn/C ≥ 5 and control grain size to 7 or finer (grain size of 8 or finer for A350 Gr.LF2, Cl.1) and limit V, Ti, Nb to ASTM A20 limits and B to 5 ppm maximum.
3. Or select an acceptable alternate material, such as the following, which includes impact testing:
   a. Forgings/Fittings: ASTM/ASME A420 Gr. WPL6 (having a grain size of 8 or finer)
   b. Flanges: ASTM/ASME A350 Gr.LF2, Cl.1 (Charpy performed on coupon taken from hub having a grain size of 8 or finer)
   c. Pipe: ASTM/ASME A333 Gr. 6 (having a grain size of 8 or finer)
4. In your company's procurement documents for CS forged fittings, flanges and pipe, request a copy of the MTR [mill test report] for each heat of material.
5. In procurement, request MTR results of impact testing of each heat of material meeting the above values or values in accordance with the material standard when included.
6. In procurement, request that the MTR include the material's Mn/C ratio indicating that it is ≥ 5.

Finally, my thanks to Barry Messer, Fluor Corp., who took the time to present such a vital topic at the spring 2016 ASME B31.3 Process Piping code meeting in Seattle. Acknowledgement and appreciation also goes to John Houben, Exxon-Mobil (corporate.exxonmobil.com), as well as the Materials Technology Institute (www.mti-global.org/) who has pulled together a team of experts that have been leading the charge on this effort.

Bill Huitt
President, W.M. Huitt Co., St. Louis, Mo.

Editor's note: The above letter is an excerpt of the full letter that can be found on www.chemengonline.com

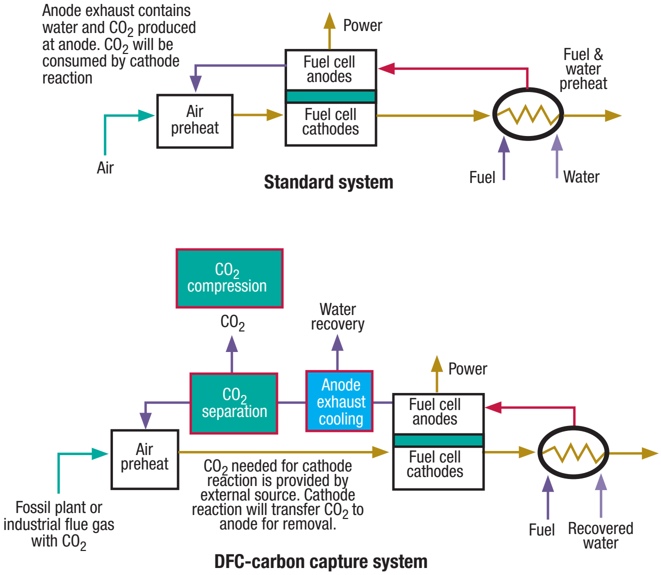
Postscripts, corrections

May, 2016, "This drum dumper is dust tight", p. 34. The photo of the drum dumper is incorrect in the print edition. The correct photo is shown here:

Flexicon

Fuel-cell-based carbon capture system can augment power generation

Post-combustion carbon-capture processes that are based on adsorption of CO_2 by amine compounds reduce the power output of coal- and natural-gas-fired power plants largely due to the energy required to regenerate the CO_2 from the adsorbent material. In another approach, carbonate fuel cells can be used to separate CO_2 from power plant exhaust streams while generating electricity and boosting the overall power output of the plant.



A new development partnership between ExxonMobil Corp. (Dallas, Tex.; www.exxonmobil.com) and Fuel Cell Energy Inc. (FCE; Danbury, Conn.; www.fuelcellenergy.com) has the goal of utilizing FCE's carbonate fuel cell technology so it can be used to separate and concentrate CO_2 from the exhaust gas of a commercial-scale natural-gas power plant.

Carbonate fuel cells produce hydrogen from natural gas and biogas, and then use the H_2 to generate electricity and water. In a carbonate fuel cell, carbonate ions are formed (along with electrons) at the anode, and these ions complete the electrical circuit across the electrolyte layer of the fuel cell stack (see figure). Since such fuel cells require CO_2 to form carbonate ions, power-plant exhaust gas — containing 5% CO_2 in the case of a natural gas plant — can be used as a CO_2 source, and the fuel cell then becomes a means of separating and concentrating CO_2 from the exhaust, explains Tony Leo, vice president of applications and technology development for FCE. "There's an internal CO_2 cycle within the carbonate fuel cell, which can be co-opted to separate CO_2 for carbon capture without the need for a regeneration step, as is the case in amine-based carbon capture," he says. As an added benefit, 70% of the oxides of nitrogen (NOx) compounds are reduced to N_2 in the electrochemical cell, Leo notes.

The ExxonMobil-FCE project for developing carbonate fuel cells for carbon capture in natural-gas plants joins an ongoing U.S. Dept. of Energy funded project to adapt FCE carbon capture technology for use in coal-fired power plants.

A 3-D printed polymer with enzymes turns methane to methanol

Scientists from Lawrence Livermore National Laboratory (LLNL; Livermore, Calif.; www.llnl.gov) have combined biology and 3-D printing to create the first reactor that can continuously produce methanol from methane at room temperature and pressure. The team removed enzymes from *methanotrophs* — bacteria that metabolize methane — and mixed them with polymers that were printed or molded into innovative reactors. "Remarkably, the enzymes retain up to 100% activity in the polymer," according to Sarah Baker, LLNL chemist and project lead. "The printed enzyme-embedded polymer is highly flexible for future development and should be useful in a wide range of applications, especially those involving gas-liquid reactions."

The research, which could lead to more efficient conversion of methane-to-energy production, was described in a recent issue of *Nature Communications*.

Edited by:
Gerald Ondrey

MAKING MORE ARA

Arcadia Biosciences Inc. (Davis, Calif.; www.arcadiabio.com) and Dupont Pioneer (Des Moines, Iowa; www.pioneer.com) recently completed field-trial validation for new safflower plants that produce high levels of arachidonic acid (ARA) oil, a high-value, specialty nutritional oil. The field validation is a key milestone for Arcadia and DuPont Pioneer in their pursuit of a new plant-based and cost-effective source of high-ARA oil. ARA is an omega-6 fatty acid that, along with certain omega-3 fatty acids, plays a critical role in neural and visual development of infants. It is one of the most abundant fatty acids in the brain, and neurological health is reliant upon sufficient levels of ARA. The oil appears as a functional ingredient in many infant nutrition products, and has been shown to provide developmental benefits similar to breastfeeding. High-ARA safflower plants will offer a more efficient source for the ingredient, and will improve manufacturing economics and encourage wider use of ARA. Arcadia's ARA safflower oil is in the late stages of product development.

EXPRESS SAMPLING

To determine the levels of polycyclic aromatic hydrocarbons (PAHs) in soil and sediment, one must first extract the compounds from a sample — a step that can take up to 16 h and require large amounts of hazardous solvents. Newer, high-temperature techniques are faster and need much less solvent, but they require expensive equipment. A cost-effective alternative has been devised by Francesc A. Es-

(Continues on p. 10)

Note: For more information, circle the 56-digit number on p. 62, or use the website designation.

teve-Turrillas and colleagues at the Dept. of Analytical Chemistry, University of Valencia (www.uv.es) — a common espresso machine.

The group percolated a soil sample in an espresso machine with a small amount of organic solvent and water. The extracted sample was then analyzed with a standard chromatography procedure to determine the level of PAHs present. The process takes only 11 s, and the results were comparable to those obtained with certified techniques. The researchers say that this study — published in a recent issue of ACS's *Analytical Chemistry* — shows that espresso makers can be used as low-cost alternatives in chemistry laboratories. They are currently testing to see whether these machines can extract pesticides, pharmaceuticals and detergents in food and environmental samples for analysis.

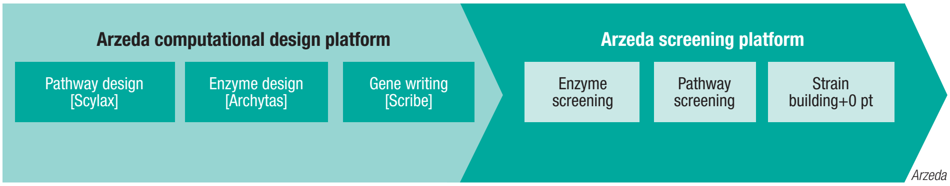
STEELMAKING

A memorandum of understanding (MoU) to jointly demonstrate optimal control technology to reduce total energy costs at a steelmaking plant has been signed by The New Energy and Industrial Technology Development Organization (NEDO; Kawasaki City, Japan; www.nedo.go.jp), the Indian Ministries of Steel (MOS) and Finance Dept. of Economic Affairs, and the Steel Authority of India Ltd (SAIL). NEDO will promote large-scale energy saving in India with the introduction of Japan's so-called Energy Center and Energy Management System (EMS).

The Burnpur plant of SAIL's integrated steelworks has been selected as the demonstration site. NEDO estimates that energy consumption, greenhouse gas emissions and energy costs are expected to be reduced by about 11% per year in the project.

(Continues on p. 11)

Computational approach streamlines industrial enzyme development



Arzeda

Computational technology from Arzeda Corp. (Seattle, Wash.; www.arzeda.com) can streamline the development of novel enzymes, as well as improve existing enzymes, for industrial fermentation. The company's proprietary computational platform, known as Archytas, uses advanced algorithms to design and screen a vast number of DNA sequences that code for enzymes with properties desirable for a targeted industrial fermentation process. Arzeda's technology creates new genes not present in nature, but that are optimal for industrial applications, explains Arzeda co-founder and CEO Alex Zanghellini. He contrasts his company's DNA screening approach with other modeling techniques, such as molecular dynamics, that use computer processing power to solve molecular mechanics equations designed to model and understand existing enzyme activity. "Our technology is able to screen through 10^{32} different combinations and generate a narrowed-down list of DNA sequence candidates that can give rise to the required enzyme properties," Zanghellini says. Then a small number of DNA sequences with the properties most likely to be useful are synthesized and tested in live vectors.

By automating and scaling up the discovery and optimization of new enzymes, Arzeda is able to access and build metabolic pathways that don't exist naturally, and apply them to industrial fermentation, where they can replace several synthesis steps using conventional chemistry. The company is currently working with several large industrial partners, including Dupont, Invista and Mitsubishi, on a host of projects. Some are aimed at developing novel traits in agricultural crops, and others are involved with industrial chemicals. Additional proprietary projects involve developing enzymes for synthesizing fine and specialty chemicals by fermentation.

P-recovery process to be demonstrated

By the end of this year, a demonstration plant will start up in the U.S. that uses an electrochemical process to recover phosphorus from wastewater, producing a fertilizer as struvite ($NH_4MgPO_4 \cdot 6H_2O$). Although the location and capacity of the plant has not yet been finalized, the plant will mark the scaleup of the patented ePhos process, which was developed and pilot-tested by the Fraunhofer Instutute for Interfacial Engineering and Biotechnology (IGB; Stuttgart, Germany; www.igb.fraunhofer.de) and licensed to Ovivo USA LLC (Austin, Tex.; www.ovivowater.com).

Unlike conventional precipitation methods, which require the addition of magnesium salts (for struvite formation) and NaOH (for adjusting the pH), the ePhos process uses a sacrificial magnesium anode to generate the required Mg^{+2} ions, while the water-splitting cathodic oxidation ($2H_2O + 2e^{-1} \rightarrow H_2 + 2OH^{-1}$) raises the pH to 9. The Mg^{+2} ions generated at the anode react with phosphates and ammonium in the wastewater and precipitate out of solution as struvite crystals that can be dried and used directly as fertilizer.

"Struvite is free of biomass and can be used directly in agriculture as a high-quality fertilizer that releases nutrients slowly," explains Iosif Mariakakis, project manager at IGB. Experiments have shown that plants' yield and nutrient uptake with the struvite product was up to four times higher than for commercially available mineral-based fertilizers, such as ammonium nitrate and triple superphosphate.

Long-term trials with the pilot plant have shown that ePhos recovers about 85% of the phosphates, on average, says Mariakakis. Energy consumption for the process is about 0.78 kWh/m^3 of wastewater, he says.

Ovivo recently licensed the technology, and is marketing the technology now in the U.S., Canada and Mexico. Meanwhile, researchers at IGB are busy developing their reactor concept further. "We plan to expand ePhos by adding processing modules that allow water-treatment plants to recover ammonium, too," says Mariakakis.

Selective conversion of plastics to waxes

A proprietary technology and patented process from GreenMantra Technologies (Brantford, Ont., Canada; www.greenmantra.ca) that produces synthetic waxes from underutilized plastic recycling streams, including films and bags, has reached commercialization. The company's first industrial-scale manufacturing plant started up in May, and can process 5,000 metric tons per year (m.t./yr) of polyolefin waste into wax products. The cornerstone of the process is a family of proprietary heterogeneous catalysts that enables extremely selective thermo-catalytic depolymerization reactions to occur, with high yields of the final product. The catalyst allows for control over the molecular weight, structural and thermal properties of resulting polymers, creating a variety of specialty waxes. Tailored for longterm use with contaminated recycling streams, the catalyst's aluminum oxide support can be regenerated back to its virgin form as needed and re-impregnated with active metals.

When compared with other chemical recycling processes, GreenMantra's process not only operates at a much lower temperature (the lower threshold of the thermal degradation point), but also avoids the randomness of the depolymerizations experienced in processes based on pyrolysis or gasification. According to technical director Domenic Di Mondo, the yield is also quite high, with conversion rates of up to 97%.

Currently, the process is run on a semi-continuous basis, where re-processed polyolefin is melted and fed into a series of parallel batch reactors. The residence time, temperature and pressure of the polymer in the reactor vessels can be adjusted based on the specific wax that is being produced. At this point, the product is cooled, purified and solidified into prills. The company hopes to move to a fully continuous basis using fixed-bed reactors, and add an additional 5,000 m.t./yr of capacity by 2017, says Di Mondo. Going forward, GreenMantra is also further developing its product portfolio to include novel polymers for use in inks, coatings and other applications.

3-D PRINTING

In partnership with Swedish startup Exmet AB (Stockholm; www.exmet.se), Heraeus GmbH (Hanau, Germany; www.heraus.com) has developed the technology for the 3-D printing of amorphous components, thereby expanding its range for special materials. Amorphous metals are very strong and yet malleable, as well as harder and more corrosion-resistant than conventional metals, says Tobias Caspari, head of 3-D Printing at Heraeus New Businesses. "Together with Exmet, we intend to open up this new class of materials for industry and 3-D printing."

Amorphous metals are suitable for an exceptional number of high-tech applications. They are energy-absorbing and scratch-

(Continues on p. 12)

proof while still having very good spring characteristics — interesting for injection nozzle diaphragms, casing for consumer electronics, or as dome tweeters for speakers, says Heraeus.

"For fifty years, the commercial success of amorphous metals has been held back by inadequate manufacturing methods. Now that changes," says Mattias Unosson, Exmet co-founder and CEO.

NEW BORIDES

Although borides are among the hardest and most heat-resistant substances on the planet, they oxidize at high temperatures, leading to a loss of the material's structural integrity. Now researchers from Drexel University (Philadelphia, Pa.; www.drexel.edu), Linköping University (Sweden; www.liu.se) and Imperial College London (U.K.; www.ucl.ac.uk) have produced an aluminum-layered boride with unique behavior at high temperatures.

To make the boride material — molybdenum aluminum boride (MoAlB) — the researchers combined a molybdenum-boron lattice with a double layer of aluminum to produce a material that is durable enough to resist oxidation at extremely high temperatures. The key to this remarkable characteristic is the material's nanolaminated structure with alternating layers of molybdenum boride and aluminum — a form the Drexel group has established a reputation for working with since its creation of "MAX phases" two decades ago.

The group also found that the material retains its high conductivity at elevated temperatures. Its melting point has yet to be determined, but preliminary results have shown it to be greater than 1,400°C.

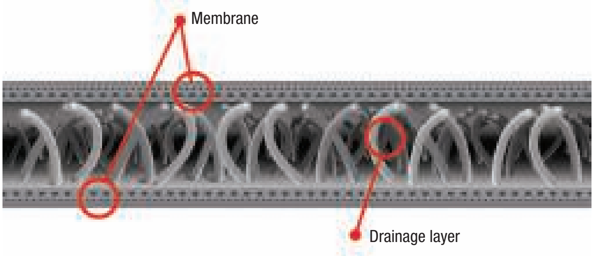
OXYBROMINATION

The oxybromination of methane into methyl bromide typically generates

(Continues on p. 13)

A next-generation membrane bioreactor

Last month at the IFAT trade fair (May 30–June 3; Munich, Germany), Huber SE (Berching: www.huber.de) and Microdyn-Nadir GmbH (Wiesbaden, both Germany: www.microdyn-nadir.de) unveiled a rotating membrane bioreactor (MBR) that utilizes membrane laminate technology. "By combining our two technologies we have created a groundbreaking product symbiosis," says Walter Lamparter, CEO at Microdyn-Nadir.



In Huber's VRM (vacuum rotation membrane) system (diagram, bottom), the membrane modules are submerged into the activated sludge and are mounted segmentally onto air tubes. The trapezoidal membrane segments are rotated through an air-induced flushing stream driven by a filter drive. The rising air bubbles are continuously cleaning the membrane laminate sheets, thus significantly reducing fouling and energy demand.

Instead of equipping the trapezoidal segments with a Nadir flat-sheet membrane welded onto a plate, as before, Huber is now using the membrane laminate technology, based on the Nadir flat-sheet membrane made by Microdyn-Nadir. "By combining our VRM technology with the unique laminate technology, we achieve a significantly higher packing density and therefore an increase in membrane area per module. Moreover, energy demand and costs can be reduced tremendously," says Oliver Rong, vice CEO at Huber.

Microdyn-Nadir's Bio-Cel membrane laminate technology (diagram, top) is neither a hollow fiber nor a plate, but rather a hollow sheet. Unlike a plate-and-frame construction, the Bio-Cel is backwashable like a hollow-fiber module, and is said to be the only module design that can be cleaned mechanically. In addition, the Bio-Cel membrane laminate technology features a self-healing mechanism, which allows the laminate to "heal" itself in less than two minutes.

Recycling waste polystyrene into membranes

Scientists from the National Chung Hsing University (Taichung, Taiwan; www.nchu.edu.tw), led by professor Ming-Yen Wey, have successfully developed an alternative route for recycling plastic solid waste. They used waste polystyrene to develop membranes suitable for processes such as carbon capture, oxygen enrichment and hydrogen purification.

They departed from three types of waste: oriented polystyrene, expandable polystyrene and high-impact polystyrene. The first two are made solely from styrene monomer, while high-impact polystyrene (HIPS) includes butadiene to increase its strength.

Samples of waste polystyrene were crushed, cleaned using ultrasonication with water and ethanol, and dried overnight at 75°C. The scientists made the membranes using a process called solution casting, whereby polystyrene is dissolved in toluene, and then the solutions are cast onto a glass slide. These were then dried overnight at 75°C to evaporate the solvent, washed in deionized water and dried again.

The decomposition temperatures of the membranes are between 400 and 440°C, and the presence of inorganic compounds do not affect them.

Gas-permeability tests showed that expandable polystyrene was the least effective for gas separation due to instabilities in the membrane structure. HIPS membranes were slightly more stable and exhibited better separation ability than the membranes made from the other two types of polystyrene. According to the scientists, this was due to the butadiene molecules.

The scientists concluded that their novel reuse route for polystyrene waste was economically and environmentally friendly.

A glass for all colors

Colloidal glasses develop structural color through constructive interference. The color can be tuned by adjusting interparticle distance, making the colloidal glasses attractive for use as color pigments for use in coatings, displays, colorimetric sensors and optical barcodes. While colloidal crystals exhibit brilliant color with wavelengths that are strongly angle-dependent, colloidal glasses with only short-range order provide dim, but angle-independent structural color due to their isotropic nature.

There are a number of ways to prepare colloidal glasses, but it is difficult to produce red color with them because a cavity-like mode from individual particles yields strong backscattering in blue, overwhelming the resonance in red from the glassy colloidal array. To develop red structural color, the optical length within particles must be shortened.

Now a group from the Dept. of Chemical and Biomolecular Engineering at the Korea Advanced Institute of Science and Technology (KAIST; Daejeon, South Korea; www.kaist.ac.kr), led by professor Shin-Hyun Kim, used inverse glassy structures to develop noniridescent colors in the full visible range. The air cavities have short optical lengths, yielding weak cavity resonance out of the visible range. Also, to provide easy material processing and high mechanical stability of the inverse glasses, the group employed photocurable suspensions containing amorphous arrays of concentrated colloids that serve as templates to produce amorphous arrays of air cavities in a polymerized matrix.

To prepare the suspensions, the group dispersed silica particles in the photocurable resin, which forms thin solvation layers on the surface. For a certain range of concentrations, the silica particles form a non-closely-packed amorphous array. The colloidal array can be rapidly captured by photopolymerizing the medium, which is then removed by selective etching, thus yielding inverse glassy structures.

The inverse glasses exhibit noniridescent structural colors under diffuse light. The colors can be tuned in full visible range by adjusting particle diameter.

High-performance composite based on biomass

Polylactic acid (PLA) is a versatile biopolymer, but its applications are somewhat limited due to its brittleness. Now, an alternative bio-based composite material has been developed that overcomes this limitation. Developed by the industry-university consortium of Hitachi Zosen Corp. (HITZ; Osaka City, www.hitachizosen.co.jp and Osaka University, under the New Energy and Industrial Technology Development Organization (NEDO; Kawasaki City, all Japan; www.nedo.go.jp), the composite is made by dynamically cross-linking and combining PLA with 10–30 wt.% of trans-polyisoprene, which is derived from the non-edible biomass of *Eucommia*, a tree native to China whose bark is used for medicines.

The material has an impact resistance value approximately 16–25 times greater than commercially available PLA. The elongation, one of the tensile properties, has also been drastically improved by a factor of approximately 9–30 times. It is expected that this biomass-derived composite material will be used as resins for 3-D printing, which has a growing global market for use in automobile interiors and components that normally are made in molding processes. Other potential applications include bio-based sporting goods, office equipment and medical devices.

The partners are investing several million dollars in a 10-ton/yr mass-production line to manufacture the composite, and expect to begin shipping products later this summer.

Making H_2 from aluminum composite waste

Last April, a demonstration plant started up for the production of hydrogen from aluminum-based composite waste. The startup marks the culmination of a project, supported by NEDO, in which Alhytec Inc. (Takaoa City, Japan; www.alhytec.co.jp) developed the process to separate the aluminum from waste composite materials and generate H_2 to be used for fuel-cell power generation at Asahi Printing Co.'s Toyama Plant. The demonstration plant has a production capacity of 2 kg/h, and the company plans to enhance the H_2 generation to up to 5 kg/h.

The system is composed of three steps, a pulper-type separator, using a high-speed rotator wing for separating plastics and aluminum; a pyrolysis furnace for decomposing the plastics and removing the aluminum; and the H_2 generator, in which the H_2 is produced by the reaction of Al in an alkaline solution. The technology is expected to find applications at printing, packaging and metals factories. ■

large quantities of unwanted products, making it unfavorable as a way to utilize natural gas for making chemicals. Now, researchers at ETH Zurich (Switzerland; www.ethz.ch) have discovered a vanadium phosphate catalyst with a high selectivity, which makes it possible to brominate methane in a single step at atmospheric pressure and temperatures below 500°C. The discovery could enable the use of CH_3Br as an alternative to synthesis gas (syngas) as the building block for making fuels or complex chemicals, such as polymers or pharmaceuticals.

Currently, methane is industrially converted into higher-grade chemicals by steam reforming, which requires high pressures (up to 30 bars) and temperatures (up to 1,000°C).

The new catalyst — described in a recent issue of *Nature Chemistry* — is said to be exceptionally stable, and resistant to corrosive halogen environments.

A BIOACTIVE FILM

Polyether ether ketone (PEEK) has mechanical properties similar to bone, making it attractive for use in spinal implants. However, PEEK doesn't bond well with bone. Now, researchers have developed a technique for coating polymer implants with a bioactive film that significantly increases bonding between the implant and surrounding bone in an animal model. The advance could significantly improve the success rate of such implants, which are often used in spinal surgeries. The work was done by researchers at North Carolina State University (Raleigh; www.ncsu.edu), the University of Cambridge (U.K.; www.cam.ac.uk) and the University of Texas at San Antonio (www.utsa.edu), and is described in a recent issue of *Materials Science and Engineering*.

LINEUP

AIR LIQUIDE
AMEC FOSTER WHEELER
AXIALL
EASTMAN
EVONIK
FERRO
FMC TECHNOLOGIES
ITALMATCH
KURARAY
LANXESS
LUKOIL
MAIRE TECNIMONT
MESSER
METOKOTE
PPG
SILURIA
SOLENIS
SOLVAY
SUMITOMO CHEMICAL
TECHNIP
UMICORE
UNIPETROL
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Plant Watch

Unipetrol breaks ground on Czech Republic's largest petrochemical project

June 10, 2016 — Unipetrol a.s. (Prague, Czech Republic; www.unipetrol.cz) has officially broken ground for the construction of a new polyethylene unit, said to be the largest investment in the history of the Czech petrochemical industry, amounting to CZK 8.5 billion (around $355 million). Inauguration of the new unit, which has a production capacity of 270,000 metric tons per year (m.t./yr), is planned in mid-2018.

Evonik starts up membrane coating facility in Germany

June 9, 2016 — Evonik Industries AG (Essen, Germany; www.evonik.com) recently started operating a thin-film composites plant to coat membranes for use in nanofiltration and gas separation at its Marl site in Germany. In the new plant, thin membrane films are coated with special silicone or other materials.

Amec Foster Wheeler wins world-scale methionine facility contract in Singapore

May 31, 2016 — Amec Foster Wheeler (London, U.K.; www.amecfw.com) has been awarded the engineering, procurement, construction management (EPCM) contract by Evonik Methionine SEA Pte. Ltd for its second methionine plant complex in Singapore. With an annual production capacity of 150,000 m.t., the plant is expected to start up in 2019.

Lukoil commissions large vacuum-gasoil conversion complex

May 31, 2016 — Lukoil (Moscow; www.lukoil.com) has fully commissioned the Oil Deep Conversion Complex in Volgograd as part of a vacuum gasoil (VGO) hydrocracking facility at the company's wholly owned petroleum refinery OOO Lukoil-Volgogradneftepererabotka. The capacity of the site, said to be Russia's largest VGO deep-conversion complex, is 3.5 million m.t./yr. In total, $2.2 billion was invested in the project.

Kuraray boosts EVAL production capacity in the U.S.

May 26, 2016 — Kuraray Co. (Tokyo, Japan; www.kuraray.us.com) plans to increase the production capacity of ethylene vinyl alcohol copolymer (EVAL) by 11,000 m.t./yr at its plant located in Pasadena, Tex. Expanded operations are expected to commence in the summer of 2018.

Lanxess expands industrial lubricant additives capacities

May 24, 2016 — Lanxess AG (Cologne, Germany; www.lanxess.com) has expanded its capacities for light-colored sulfur carriers at its sites in Mannheim, Germany and Kallo, Belgium. Light-colored sulfur carriers are used as additives in formulating high-performance metalworking fluids and gear oils. The expansion in Mannheim increases production capacity by 20% and represents an investment of €1.5 million.

Sumitomo Chemical to build new methionine production line in Japan

May 19, 2016 — Sumitomo Chemical Co. (Tokyo; www.sumitomo-chem.co.jp) plans to expand its production capacity for the feed additive methionine by adding a new production line in Niihama City, Ehime Prefecture, Japan. With this expansion, the company will increase its methionine production capacity by around 100,000 m.t./yr. The new facility is scheduled for completion in mid-2018.

Mergers & Acquisitions

Westlake agrees to acquire Axiall for $3.8 billion

June 10, 2016 — Westlake Chemical Corp. (Houston; www.westlake.com) and Axiall Corp. (Atlanta, Ga.; www.axiall.com) have entered into a definitive agreement under which Westlake will acquire all of the outstanding shares of Axiall for an enterprise value of approximately $3.8 billion. The transaction is expected to be completed by the fourth quarter of 2016.

PPG to acquire coatings service provider MetoKote

June 9, 2016 — PPG Industries, Inc. (Pittsburgh, Pa.; www.ppg.com) has reached a definitive agreement to acquire coatings-services business MetoKote Corp. (Lima, Ohio) and its affiliates. The transaction is expected to close in the third quarter of 2016. MetoKote operates onsite services applying coatings to customers' manufactured parts.

Italmatch enters Americas markets with Compass Chemical acquisition

June 7, 2016 — Italmatch Chemicals Group (Genova, Italy; www.italmatch.it) has acquired Compass Chemical International LLC (Smyrna, Ga.; www.compasschemical.com), a producer of organophosphonates, polymers and other specialty additives for water-treatment and oil-and-gas applications. The acquisition will enable Italmatch to operate in the Americas markets.

Solenis' Australian subsidiary acquires Nuplex Pulp & Paper

June 6, 2016 — Solenis (Wilmington, Del.; www.solenis.com), through its Australia subsidiary Solenis Australia Pty Ltd., completed the acquisition of the business assets of Nuplex

Pulp & Paper from Nuplex Industries Australia Pty Ltd. This business will be integrated into Solenis as part of its strategy to broaden its process chemicals offerings.

Solvay purchases Eastman stake in cellulose acetate JV

June 2, 2016 — Solvay S.A. (Brussels, Belgium; www.solvay.com) completed the purchase of Eastman Chemical Co.'s (Kingsport, Tenn.; www.eastman.com) share in their former U.S. joint venture (JV) Primester. With this purchase, Solvay becomes the sole owner of the JV's cellulose-acetate flake plant in Kingsport. Eastman will provide the longterm supply of basic utilities and raw materials to the plant.

Maire Tecnimont and Siluria sign joint collaboration agreement

June 2, 2016 — Maire Tecnimont S.p.A. (Milan, Italy; www.mairetecnimont.com) and Siluria Technologies (San Francisco, Calif.; www.siluria.com) have entered into a joint collaboration agreement to bring to the marketplace a process to convert natural gas directly into commodity chemicals and derivatives. In conjunction with the joint collaboration agreement, Maire Tecnimont has made a minority investment of $10 million in Siluria.

Ferro completes acquisition of glass-coatings manufacturer

June 2, 2016 — Ferro Corp. (Mayfield Heights, Ohio; www.ferro.com) has completed the acquisition of Pinturas Benicarló, S.L. for €15.0 million. The acquisition adds new waterborne coatings technology to Ferro's Performance Colors and Glass unit.

Messer finalizes takeover of Air Liquide assets in Hungary

June 1, 2016 — The Hungarian subsidiary of Messer Group (Bad Soden, Germany; www.messergroup.com) has finalized the purchase of Air Liquide Hungary Ipari Gáztermelö Kft. The fixed assets include an onsite air-separation unit, two nitrogen generators, a filling plant for gas cylinders, plus tankers, customer tanks and steel cylinders.

Umicore to divest its Zinc Chemicals business

June 1, 2016 — Umicore N.V. (Brussels, Belgium; www.umicore.com) reached an agreement to sell its Zinc Chemicals business unit to U.S. private equity firm OpenGate Capital. The transaction places an enterprise value of €142.4 million on the business and is expected to close in the second half of 2016. Zinc Chemicals encompasses eight industrial sites in Europe and Asia.

Technip and FMC Technologies to combine, creating $13-billion firm

May 19, 2016 — Technip (Paris, France; www.technip.com) and FMC Technologies, Inc. (Houston; www.fmctechnologies.com) announced that the companies will combine to create a global company, which will be called TechnipFMC, with an equity value of $13 billion. Each company's shareholders will own around 50% of the combined company. The transaction is expected to close early in 2017, subject to customary approvals. ■

Mary Page Bailey

Background photo: Jing Wang, PSU

Engineering surfaces to repel all liquids

Nature-inspired surfaces are being developed that are not only highly repellent to water, but are even superomniphobic

IN BRIEF

DOUBLE-DIGIT GROWTH

IMITATING NATURE

BEYOND THE LOTUS

SUPEROMNIPHOBIC

OTHER DEVELOPMENTS

Although hydrophobic materials have been in use for many years, advances in nanotechnology are causing a revolution in the coatings and surface-treatment field. As a result, materials are now being developed that are extremely repellent to water (superhydrophobic), oils (superoleophobic) and, most recently, all liquids (superomniphobic). Such liquid-repulsive materials are promising substantial benefits in many different sectors of the chemical process industries (CPI), as well as in many consumer products. The market for such materials is booming.

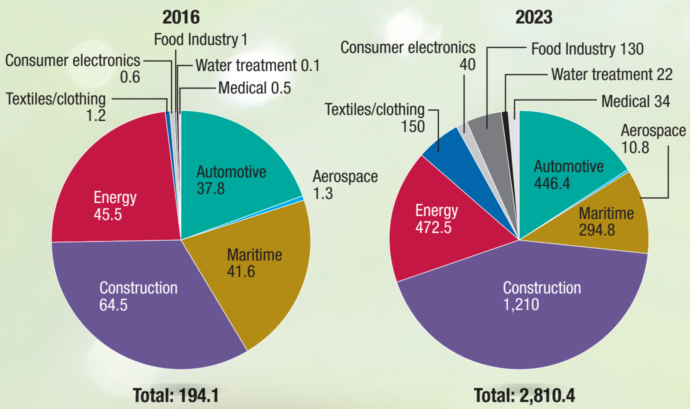
Double-digit growth

In the next eight years, the total revenue for hydrophobic materials is forecast to increase by nearly a factor of 15, from $194 million in 2016 to $2.8 billion in 2023, according to Lawrence Gasman, a consultant at n-tech Research (Glenn Allen, Va.; www.ntechresearch.com), and principal author of the report, "Hydrophobic Coatings and Surfaces: 2016–2023," which was published last November. The most promising areas of growth are forecast to be in the water-treatment sector, the food industry and in textiles and clothing, but there's money to be made in the more traditional markets, such as construction and automotive sectors (see Figure 1).

The favorable market is due to a number of factors, explains Gasman. Although hydrophobic materials have been used for many years, producers continue to improve the performance characteristics, as well as adding multifunctional properties to the coatings and surface-treatment technologies. As a result, they can charge more for their products, while the users gain the additional benefits. In the marine sector, these benefits include reduced friction and fouling on ship hulls, which can significantly reduce fuel consumption. In the solar-power sector, anti-reflection and self-cleaning properties can improve the photo-conversion efficiency while reducing maintenance costs. And everyone these days can understand the "advantage" of being able to use a cell phone while waiting for a train on a rainy day.

Realizing the potential market demand for "smarter" coatings and functionalized surfaces, considerable effort is now underway to develop new and advanced materials. That means imparting not only superhydrophobicity to a surface, but making it more resilient to abrasion, high temperatures and pressures.

FIGURE 1. The eight-year forecast for hydrophobic materials revenue (in million $) is broken down here by application sector (Source: n-tech Research)



Imitating nature

The self-cleaning ability of the leaves of plants — especially the lotus plant (*Nelumbo;* background photo) has been well understood since the 1970s, when the term "lotus effect" was first coined by German botanist Wilhelm Barthlott, who used electron microscopy to observe the nanostructure of such plants. The high hydrophobicity of the leaves is due to papillae on the surface — hair-like nano-scale textures within the epidermis — and epicuticular waxes on top. This double structure causes water to simply bead up into a sphere and roll off, carrying dirt and debris with it.

Since then, the term LotusEffect has been

TABLE 1. NEW COMPANIES WITH SUPERHYDROPHOBIC MATERIALS			
Company	**Location/website**	**Application/product**	**Comments**
Joma International	Nyborg, Norway www.joma-int.com	Superhydrophobic nanocoatings with photocatalytic properties for concrete and stone surfaces	
LiquiGlide	Cambridge, Mass. www.liquiglide.com	Self-healing, non-stick coating for inside of condiment bottles	Spinoff from MIT
Maxterial	Richmond, Va. www.maxterial.com	Superhydrophobic metals; potential applications for heat exchangers, condensers and other types of equipment	Spinoff from Virginia Tech
nanoShell	Devon, U.K. www.nanoshell.co.uk	Self-cleaning nanocoatings for solar panels, metals and wood	
nGiMat	Atlanta, Ga. www.ngimat.com	Self-cleaning coatings for architectural glass, automotive glass, solar cells and other specialty products	Combustion chemical vapor deposition (CCVD) process to deposit thin films with nanostructured surfaces
P2i	Milton Park, U.K. www.p2i.com	Water-repellent coating on electronics devices (smart phones, tablets, and so on), filtration media	Hydrophobic nanocoating made by pulsed plasma deposition process
RepellX	Nämpnäs, Finland www.repellx.com	Clothing, shoes, furniture	Spray nanotechnology-based coating that renders materials superhydrophobic
Roechling	Mannheim, Germany www.roechling.com	Wall coverings, such as in hospitals	TroBloc M is a superhydrophobic coating with antimicrobial effect
SLIPS Technologies	Cambridge, Mass. www.slipstechnologies.com	Slippery, liquid-infused porous coatings (anti-icing, anti-biofouling, anti-graffiti, anti-coagulation	Spinoff from Harvard University
Vestagen Protective Technologies	Orlando, Fla. www.vestagen.com	Liquid-repellent textiles for healthcare	Vestex is an active barrier fabric that incorporates a highly repellent fluid barrier and a durable antimicrobial

trademarked by Sto AG (Stuehling, Germany; www.sto.com), one of the first companies to capitalize on this phenomenon. Sto first launched its self-cleaning Lotusan brand of coating in 1999, and in 2005, introduced StoCoat Lotusan, a spray-on waterproof air barrier. Last April, Sto launched its next-generation StoCoat Lotusan coating for building facades.

In addition to major producers, universities and research institutions have been actively working in this field, and a number of relatively new start-up and spin-off companies have been formed to commercialize new technology based on superhydrophobic materials (Table 1).

Beyond the lotus: omniphobic

Superhydrophobics are a specific class of liquid-repellent surfaces that consist of micro- or nanoscale surface textures to trap a thin layer of air against impinging liquid droplets, explains Tak-Sing Wong, assistant professor of mechanical engineering at Penn State University (PSU; University Park, Pa.; www.psu.edu). As long as the air layer is maintained, superhydrophobic surfaces show excellent liquid-repellent property, and many researchers in the field have demonstrated that superhydrophobic surfaces can be used for self-cleaning, anti-icing, and drag-reduction purposes, says Wong.

However, these superhydrophobic surfaces will fail under high-pressure or temperature environments because the liquid droplets can penetrate into the surface textures and remove the air layer. To resolve this issue, a new class of liquid-repellent engineered surface — inspired by the *Nepenthes* pitcher plant — has been developed in the recent years including slippery liquid-infused porous surfaces (SLIPS). Instead of trapping an air layer like the superhydrophobic surfaces, these surfaces utilize micro- or nano-scale surface textures to trap a thin layer of liquid lubricant, and create extremely slippery surface against other immiscible fluids, explains Wong.

Wong was one of the co-inventors of SLIPS technology while a postdoc at Harvard University (Cambridge, Mass.; www.harvard.edu). The technology has since been licensed to SLIPS Technologies Inc. (Cambridge, Mass.; www.slipstechnologies.com), which is working toward commercial applications (*Chem. Eng.*, November 2015, p. 10). In 2014, the company received a financial boost with a $3-million Series A financing, spearheaded by BASF Venture Capital GmbH (Ludwigshafen, Germany; www.basf-vc.com).

Alongside the investment, BASF signed a joint-development agreement with SLIPS Technologies to develop SLIPS-coated thermoplastics with primary focus on thermoplastic polyurethanes (TPUs). TPUs are used in a variety of applications, such as sports and leisure footwear, industrial cables as well as specialty films.

More recently (last year), Wong's group at PSU has developed a new type of liquid-repellent surface, known as slippery rough surfaces (SRS) by combining the unique features of SLIPS and superhydrophobic surfaces (Figure 2). Since these liquid-infused surfaces are more stable under high pressure and temperature conditions, they can be used for applications such as condensation for heat exchangers to rapidly remove the heat from the surfaces by shedding off the condensed liquid droplets. A recent study has shown that these surfaces can improve heat transfer efficiency by at least ~100% as compared to other hydrophobic or superhydrophobic surfaces, says Wong.

Other important applications that would benefit from these engineered surfaces include anti-biofouling coatings for medical devices, heat exchangers for power plants, refrigeration or desalination facilities, as well as self-cleaning materials and fabrics.

Although Wong and his colleagues at PSU are mostly focused on fundamental research on these engineered surfaces, they have a number of patent-pending technologies that are available for licensing for interested industrial partners.

Superomniphobic

While the SLIPS and SRS technologies utilize an encapsulated liquid to impart hydrophobic or omniphobic properties, another approach has been taken by researchers at the UCLA

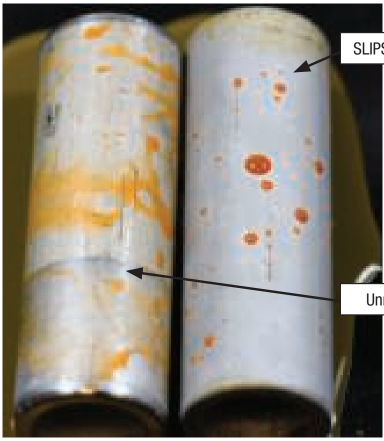
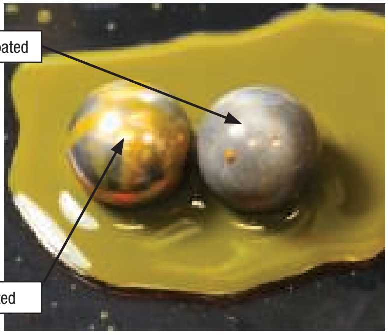



FIGURE 2. These photos demonstrate the ability of SLIPS coatings on stainless-steel pipe (left) and ball bearings (right). The liquid is octane that has been dyed yellow (Source: Jing Wang, PSU)

Henry Samueli School of Engineering and Applied Science (Calif.; www.ucla.edu), who have created what is said to be the first surface texture that can repel all liquids, no matter what material the surface is made of. Unlike other materials that combine both chemical and physical properties for the desired effect, the UCLA design relies only on the physical attributes of the texture on the surface.

The UCLA engineers formed a surface covered with microscale flat-head "nails," (*Chem. Eng.,* January 2015, p. 12). On this engineered surface, even completely wetting liquids roll around like a ball and slide right off when the surface is tilted.

The same microscale pattern can be made on surfaces of glass, a metal and a polymer. In each case, the engineered surface super-repelled water, oils and many solvents — including perfluorohexane, the liquid with the lowest known surface tension, says Chang-Jin Kim, a UCLA professor of mechanical and aerospace engineering.

Kim is currently working on a joint-research project with the Korean Institute of Machinery and Materials (KIMM; Daejeon, South Korea; http://kimm.plani.co.kr) to further develop the machinery needed to scaleup the production process.

Meanwhile, a new class of highly fluorinated polymers is being developed at the Institute of Microstructure Technology (IMT), Karlsruhe Institute of Technology (KIT; Karlsruhe, Germany; www.kit.edu). Dubbed "fluoropore," the material combines the chemical properties of fluoropolymers with a nano-scale texture to create a surface that is super repellent to both oil and water. The material is being developed under a €2.85-million project funded by Germany's Ministry of Education and Research (Bonn, Germany).

Other recent developments

A new class of superhydrophobic nanomaterials that avoids the use of hazardous fluorocarbons has been created by a team of researchers from Rice University (Houston; www.rice.edu), the University of Swansea, the University of Bristol and the University of Nice Sophia Antipolis. Led by Rice chemistry professor Andrew Barron, the team has developed a material that is inexpensive, nontoxic and can be applied to a variety of surfaces by conventional spray- or spin coating.

The coating is made from aluminum-oxide nanoparticles that are modified by highly branched carboxylic acids. When applied as a coating, the modified alumina nanoparticles agglomerate to create a microstructure that mimics the papillae of the lotus leaf, says Barron.

At Oak Ridge National Laboratory (ORNL; Tenn.; www.ornl.gov), work continues on developing hydrophobic glass coatings that have been inspired by the self-cleaning, superhydrophobic property of the lotus leaf and the anti-reflective characteristics of the moth's eye. Such coatings are expected to improve the performance of solar panels, windows and other products. For solar panels, the suppression of reflected light translates into a 3.6% relative increase in light-to-electricity conversion efficiency, says ORNL.

The coatings are fabricated by a process that produces a surface with a porous 3-D network of high-silica glass resembling microscopic coral, according to ORNL chemist Tolga Aytug. The new coating also is distinguished by its good impact abrasion resistance, he says. "This quality differentiates it from traditional polymeric and powder-based counterparts, which are generally mechanically fragile," explains Aytug. "We have shown that our nanostructured glass coatings exhibit superior mechanical resistance to impact abrasion — like sandstorms — and are thermally stable to temperatures approaching 500°C."

Another nature-inspired nanomaterial targeting self-cleaning smart windows is being developed by researchers at University College London (U.K.; www.ucl.ac.uk), as part of a 2.5-year project receiving around £100,000 in support from the Engineering and Physical Sciences Research Council (EPSRC; Swindon, U.K.; www.epsrc.ac.uk). In prototypes, the glass is superhydrophobic due to the conical design of nanostructures engraved on the surface. In addition, the glass is coated with a thin (5–10 nm) film of vanadium dioxide, which stops thermal radiation from escaping during cold periods, while preventing the passage of infrared radiation from the sun during hot periods. The design of the nanostructures also gives the windows the same antireflective properties found in the eyes of the moth.

The UCL team estimates that the windows could reduce a heating bill by 40%, with the added benefit of drastically reducing the cost for cleaning skyscraper windows. Such smart windows could reach the market within 3–5 years, says EPSRC.

Last February, Spectra-Physics (Santa Clara, Calif; www.spectra-physics.com) introduced ClearSurface, a patent-pending femtosecond laser process for surface functionalization. The process enables the patterning of high-resolution shapes, each with individually tailored surface properties. With the new process, the degree of wettability can be controlled from superhydrophobic to superhydrophilic, says the company. ■

Gerald Ondrey

Defining Sustainability in the Chemical Process Industries

This article examines the measures — both global and local — that chemical processors are taking to instill sustainability into everyday operations

SABIC

FIGURE 1. SABIC's United CO_2 purification plant captures carbon dioxide from an ethylene glycol process and distributes it as a raw material to other production units

IN BRIEF

MAKING USE OF CO_2

CORPORATE INTEGRATION

INDUSTRY COLLABORATION

WORKFORCE SUSTAINABILITY

SUSTAINABILITY IN ALL STAGES

Although discussions about sustainability in the chemical process industries (CPI) are usually geared toward making processes more environmentally sound, there are a number of aspects that encompass longterm sustainability for processors. These may include safety, personnel, data management and activism in the community. This article highlights some recent sustainability endeavors from across the CPI.

Making use of CO_2

Reducing carbon dioxide (CO_2) emissions has become a cornerstone of sustainability plans, but concerns about CO_2 are not a recent development. With origins dating back 30 years, Covestro AG's (Leverkusen, Germany; www.covestro.com) Dream Production project has been investigating the feasibility of utilizing carbon from CO_2 gas as a chemical building block. A major challenge is CO_2's inert, stable nature, which makes it unlikely to react with other substances. In cooperation with the CAT Catalytic Center in Aachen, Germany, the Dream Production team discovered a zinc-based catalyst that enables efficient reactions between high-energy epoxides and CO_2 without any cumbersome side reactions. The result is the incorporation of CO_2 into polyols — important precursor chemicals that are typically petroleum-based. This catalysis breakthrough led the company to invest €15 million in a manufacturing plant in Dormagen, Germany that uses CO_2 to produce a range of polyols for flexible foams. Operations at the plant, which has a production capacity of 5,000 metric tons per year (m.t./yr), commenced at a grand opening ceremony on June 17, 2016. The CO_2 is sourced from a neighboring ammonia plant, effectively taking the CO_2 that would be released as a greenhouse gas and putting it back into the production process. The site-sourced CO_2 also offsets the portion of petroleum-based raw materials required.

Covestro is confident in the scalability of the process, and also plans to license the technology to other polyol producers. While the Dormagen plant is currently focused on foam production, other types of novel plastics could also be manufactured. Currently, researchers are developing a similar continuous process to manufacture CO_2-based polyether carbonate polyurethanes, which are precursors for elastomers. Individual batches of the material have been produced at laboratory scale. The company is particularly excited about the future opportunities of the Dream Production process, says Covestro chief sustainability officer Richard Northcote. "It opens a whole new arena of carbon chemistry. If we can use it in mattress foam, where else can we use it?"

One of the flagship projects of Saudi Basic Industries Corp. (SABIC; Riyadh, Saudi Arabia; www.sabic.com) is the CO_2 utilization and purification plant at the United site in Jubail, Saudi Arabia, which was completed in 2015 (Figure 1). The facility, said to be the world's largest CO_2 purification plant, captures CO_2 byproduct from the concentrated vent streams of an ethylene glycol (EG) production unit. The captured CO_2 is compressed and purified, and then transported through a 25-km pipeline grid to affiliate sites, where the CO_2 serves as a feedstock. The United plant uses a patented process to capture and purify up to 500,000 m.t./yr of CO_2 from the EG process. The plant has been running since late 2015, and SABIC anticipates reaching full operating rates during 2016. While the purified CO_2 is currently supplied to affiliate processors making urea, methanol and 2-ethylhexanol, the company says that the CO_2 is of high enough purity for use in the food and medical industries. Along with CO_2, the purification process can be designed to produce a stream of purified water suitable for boiler feedwater.

Corporate integration

To view sustainability from an overarching, company-wide standpoint, Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) takes a holistic approach. "We set sustainability goals and targets at the corporate level, and they are driven across the company through the leadership of our Sustainability Council," explains Eastman director of sustainability Cathy Combs. Consisting of five senior executives representing a cross-section of the company, the Sustainability Council was established in 2010. "Our sustainability strategy continues to evolve, and we have streamlined our goals into a scorecard of aspiration goals intended to drive continuous improvement," says Combs.

To address the sustainability performance of the company's product portfolio and to create a corporate-wide appraisal system, Clariant (Muttenz, Switzerland; www.clariant.com) developed the Portfolio Value Program (PVP) beginning in 2013. The program contains 36 sustainability criteria and focuses on assessment and continuous improvements of the product portfolio. Taking the PVP a step further, Clariant has introduced the EcoTain concept, which the company applies to products and solutions that are deemed to have best-in-class attributes and sustainability advantages for customers. "Our approach not only considers the footprint of our products," explains Joachim Krueger, senior vice president for corporate sustainability and regulatory affairs, "but also the benefits as well." Based on the PVP screening, EcoTain products must demonstrate benefits in multiple lifecycle phases and not pose adverse effects to the environment or public health. Currently, around 120 products are classified as EcoTain labeled. Products that fall short in the portfolio screening are placed on an improvement roadmap and opportunities for enhancement, substitution or even discontinuation are evaluated, says Krueger. "I am convinced," he added, "that when you are really committed to becoming a sustainable company, you cannot exclude the option of eventually discontinuing a specific product or process because of its sustainability profile." In these cases, using the PVP, the company sees an opportunity to develop a more sustainable alternative product. "One thing is clear," notes Krueger, "sustainability fuels innovation."

Clariant

FIGURE 2. Palm oil is a major raw material in the specialty-chemical supply chain, and global efforts are underway to encourage its sustainble cultivation

Industry collaboration

Collaboration among the many parties involved in the CPI value chain is crucial for ensuring sustainability. Processors, vendors, suppliers and customers must all work in tandem to bring about change. Collaboration among competitive companies on large-scale projects, such as the ongoing Solar Impulse aircraft project, further represents an underlying commitment to sustainability. "What a fantastic example of chemistry overcoming issues," said Covestro's Richard Northcote of Solar Impulse. Covestro has teamed up with industry partners like Solvay S.A. (Brussels, Belgium; www.solvay.com) to provide advanced materials for Solar Impulse's lightweight solar-powered aircraft. Northcote emphasizes the importance of industrial collaboration to sustainability, noting: "The more we can work together as an industry, the more we can generate the huge impact society expects. Solar Impulse is a great example of what we can do if we work together. I have every confidence in our industry being a huge part of the solution."

Another example of a cross-industry collaboration tackling a challenging issue is Clariant's work with the SPOTS (Sustainable Palm Oil and Traceability with Sabah Small Producers) initiative, which brings Clariant together with agribusiness company Wilmar International Ltd., cosmetics giant L'Oreal and Malaysian social enterprise Wild Asia. The aim of the SPOTS collaboration is to encourage certification and supply-chain traceability among palm-oil producers in the Sabah region of Malaysia, while also increasing productivity by 20% by 2020. Palm oil, Clariant's most widely used renewable raw material, is a topic of public debate due to the adverse social and environmental impacts of its cultivation from palm tree fruits (Figure 2). Along with ensuring that Clariant's palm-oil supply chain is certified by the Roundtable on Sustainable Palm Oil (RSPO), the project will also benefit small-scale palm-oil producers by giving them access to global markets and introducing more sustainable cultivation practices. The use of sustainably sourced raw materials is one of the criteria required for a product to meet Clariant's EcoTain label. In July 2014, Clariant's Gendorf, Germany production site was successfully certified according to the RSPO Mass Balance supply-chain standard. The company plans to have all relevant production sites RSPO certified by December 2016.

Workforce sustainability

On a smaller scale, organizations are also recognizing the importance of individuals to sustainability goals, particularly in the areas of safety and workplace development. "Companies should be focused on people as a core component of sustainability," says Suresh Sundaram, senior vice president of product and market strategy at Aspen Technology (Burlington, Mass.; www.aspentech.com). "Over the next few years, the industry is expected to see a turnover of the workforce with a newer generation of engineers, as the more seasoned employees retire." The key to long-term workforce sustainability, explains Sundaram, is balancing operational strategy with market demand and reliance on employees. "Companies need to ensure that their strategies include investment in cutting-edge technologies, brain power and skills to give their businesses a clear advantage in a turbulent marketplace," Sundaram continues.

BASF SE (Ludwigshafen, Germany; www.basf.com) is looking to the next generation of engineers to help instill sustainability into the workforce through its investment in the BASF Sustainable Living Laboratory at Louisiana State University (LSU; Baton Rouge, La.; www.lsu.edu). In May, BASF selected the lab's first researcher-in-residence, Kevin McPeak, assistant professor in LSU's chemical engineering department, who will lead a research group in developing a visible-light-powered water-disinfection system. "The lab advances science and engineering education in the region while engaging creative minds to innovate sustainable solutions," says BASF. The project is part of BASF's ongoing workforce-development activities in the U.S. Gulf Coast region.

McPeak's work at the Sustainable Living Laboratory involves visible-light-driven advanced oxidation processes (AOPs) for environmental remediation. "Ultimately, he will develop a visible-light-driven water disinfection system using plasmonic-assisted-photo-Fenton catalysis," explains BASF. These AOPs are set apart from other solar-driven water-purification technologies that rely on ultraviolet light (representing just 5% of the spectrum) because they will utilize the much larger visible range of sunlight (over 40%). The technology will provide a low-cost, efficient method for photo-inactivation of waterborne pathogens, says BASF.

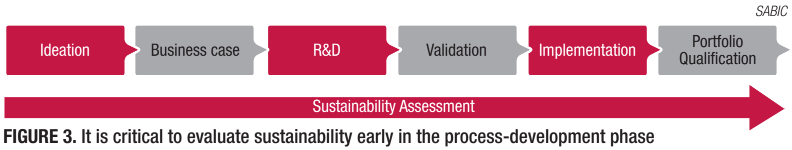


FIGURE 3. It is critical to evaluate sustainability early in the process-development phase

Sustainability in all stages

Many companies cite innovation as a core value with regard to both economics and sustainability. In May, SABIC inaugurated a research center in Geleen, the Netherlands that is focused on sustainability projects for the architectural and mass-transportation sectors, including weight reduction, energy efficiency and the integration of photovoltaic panels. For all new initiatives at the company, a sustainability assessment is conducted in the early stages and remains ongoing throughout the development phase (Figure 3). "The entire lifecycle is thoroughly considered and carefully examined. Passing a quantitative threshold is a prerequisite in order to proceed," explains a SABIC representative.

Aspen's Suresh Sundaram reiterates the importance of innovation and technology development over the lifetime of assets: "For an asset to remain viable over the term of its useful lifespan, it must be continually improved over time." He suggests that data management is a crucial pillar for sustainability, since it can introduce significant efficiencies into operational decision-making, requiring fewer resources and less time to complete tasks. With proper data management and analysis, he says, "Sustainability is enhanced through more efficient use of energy and less raw-material waste, which overall improves quality."

Evaluating sustainability through the lens of data management and process development means that some degree of standardization is necessary. In May, under a work item within ASTM International, the National Institute of Standards and Technology (NIST; Gaithersburg, Md.; www.nist.gov) announced the creation of a new international standard for characterizing the environmental aspects of manufacturing processes. ASTM E3012-16 provides guidance to help manufacturers consider their processes one by one, capturing the environmental impacts and identifying opportunities to be more sustainable. "While previous standards are a useful first step and help in developing a management approach to sustainability, they fall short of providing specific guidance for manufacturers to really dive deeply into their processes and find opportunities for improvement at that level," explains K.C. Morris, leader of the Information Modeling and Testing Group in NIST's engineering laboratory. The standard, which was co-developed by manufacturers, breaks processes into unit manufacturing process models and promotes development that can link manufacturing information and analytics for calculating desired environmental performance measures. "The standard format defined in ASTM E3012-16 provides a basis for ensuring that a consistent set of details are covered and that they are covered consistently. This consistency will allow for better comparison, more reuse, and, in the end, more reliable results," says Morris.

For the CPI, ASTM E3012-16 will help to provide value in the form of facilitating communication among stakeholders and expediting decision-making processes. NIST believes the standard may be of particular interest to software providers in the CPI. Morris emphasizes that the standard's purpose is not to dictate sustainability goals, but rather to highlight the need for such goals to be defined specifically for an individual process. "By establishing that rigor, one should see opportunities for improvement and have a basis for understanding the implication of using a particular process in the future."

It is clear that constant innovation and evaluation are crucial to ensure sustainability in the CPI, whether with regard to environmental and social concerns, resource efficiency, business practices or safety. Eastman's Cathy Combs sums it up thusly: "The bottom line is that sustainability is a continuous journey, and we are constantly re-evaluating our current business practices to determine how we can improve." ■

Mary Page Bailey

Gearing Up for Protection Against Chemicals

The CPI requires more innovative and comfortable chemical-resistant clothing, goggles and gloves to protect workers

IN BRIEF

MULTI-THREAT PROTECTION

A PRIMER ON PPE SELECTION

WORKER COMFORT

DuPont

FIGURE 1. DuPont'sTychem ThermoPro offers triple-hazard protection from liquid chemical splash, flash fire and electric arc

The purpose of chemical protective clothing (CPC) is to shield and protect workers from chemicals. However, explains Sally J. Smart, a Certified Safety Professional and technical safety specialist with Grainger (Lake Forest, Ill.; www.grainger.com), there is no one item or even a single combination of protective equipment and clothing that is capable of protecting chemical workers from all chemicals in all applications. "It's also important to remember that CPC itself is capable of creating wearer hazards, such as heat stress or psychological stress," she says. "It gets hot in encapsulated suits and some people don't like to be encapsulated because they can't hear, see, move or communicate well."

For this reason, every manufacturer of CPC is working on how to better protect workers while making them more comfortable. "These are key issues in the industry," notes Smart. "How do we make fabrics and garments lighter and more breathable, yet more chemical resistant? How do we improve vision? How do we improve mobility and dexterity?"

As a result, there are many new and improved chemical-resistant items currently available and many more on the horizon. The two biggest trends in CPC at the moment are multi-threat protection in a single garment, which can help increase worker safety and comfort by limiting the number of garments they have to don, and products designed to enhance worker comfort, thus encouraging employees to properly and consistently use the provided equipment.

Multi-threat protection

"There is a desire for multi-threat protection in a single garment because many chemical workers are exposed to double threats, such as chemical and flame hazards or particles and low visibility," says David Dom-

A PRIMER ON PPE SELECTION

Personal protective equipment (PPE) is intended to provide protection from contact with chemicals or other hazards that could result in injury to the respiratory system, skin, eyes, face, hands, feet and hearing of workers. However, the lack of standards or guidelines specifically aimed at selection of PPE and chemical protective clothing (CPC) for chemical facilities often makes choosing the right level of protection for workers in the chemical process industries (CPI) a confusing and daunting task.

Guidelines and regulations

Occupational Safety and Health Administration (OSHA, Washington, D.C.; owww.sha.gov) provides a basic standard, 1910.132, outlining general requirements for the selection and use of PPE. The basic standard describes four levels of protection, A through D, and specifies, in detail, the equipment and clothing required to adequately protect the wearer at corresponding danger levels.

According to Kyle Kerbow, director of product management with Lakeland Industries (Ronkonkoma, N.Y.; www.lakeland.com), Level A protection is required when the greatest potential for exposure to hazards exists and when the greatest level of skin, respiratory and eye protection is needed. Here, total encapsulation in a vapor-tight chemical suit with positive-pressure, full face-piece apparatus (self-contained breathing apparatus; SCBA) or positive-pressure supplied air with escape SCBA and appropriate accessories are required.

Level B situations demand the highest degree of respirator protection, but a lesser need for skin protection. Thus, SCBA or positive-pressure supplied air respirators with escape SCBA, plus hooded chemical-resistant clothing (such as overalls and a long-sleeved jacket, coverall, a one- or two-piece chemical-splash suit or disposable chemical-resistant coveralls) are needed.

Level C protection is required when the concentration and type of airborne substances is known and the criteria for using air-purifying respirators is met. Kerbow says typical Level C equipment includes a full-face, air purifying respirator, inner and outer chemical-resistant gloves, hard hat, escape mask and disposable chemical-resistant outer boots.

Level D protection is the minimum protection required and may be sufficient when no contaminants are present or work operations preclude splashes, immersion or the potential for unexpected inhalation or contact with hazardous levels of chemicals. Level D protective equipment may include gloves, coveralls, safety glasses, face shield and chemical-resistant, steel-toe boots or shoes.

Within these OSHA general guidelines for PPE, additional standards proposed and developed by the National Fire Protection Association (NFPA; Quincy, Mass.; www.nfpa.org) and the American Society for Testing and Materials (ASTM) were accepted by OSHA.

Regarding those additional standards, NFPA Standards 1991 and 1992 would be of special interest to chemical processors, says Kerbow, because they set performance requirements for totally encapsulated vapor-tight chemical suits and include rigid chemical and flame resistance tests, permeation tests and liquid splash tests against a list of challenging chemicals. Also of interest, ASTM F739 Standard Test Method for Permeation of Liquids and Gases through Protective Clothing Materials under Conditions of Continuous Contact provides information on how long a fabric "holds out" a specific chemical. "Processors can use this data for the chemicals they are using to decide which fabrics will protect against that chemical," explains Kerbow.

While these standards and guidelines outline the basics, they are just that — basic guidelines. Obviously the required garments will vary widely from industry to industry and, within industries, from facility to facility, depending upon what is being processed and other hazards specific to a facility or process. Chemical processing facilities will usually require a specialized variation of PPE, known as chemical protective clothing.

Conducting a hazard assessment

So, how does a processor decide specifically what is needed to protect their workers? According to David Domnisch, global marketing manager for Tyvek protective apparel with DuPont (Wilmington, Del.; www.dupont.com), a hazard assessment is a crucial part of the PPE puzzle. OSHA's general requirements state that an employer must assess the workplace for hazards and determine what PPE is needed to protect their workers. The assessment must be formalized, documented and certified and requires employers to look at all operations and tasks and determine what hazards are present. A proper PPE hazard assessment includes all parts of the body, the hazards that affect those body parts that can't be controlled by any other means (elimination or substitution, engineering controls or administrative controls), and then what type of PPE is required.

Available selection assistance

While most facilities have in-house environmental health and safety groups or on-staff certified industrial hygienists that can perform the hazard assessment and select the right level of PPE and CPC, many providers of PPE provide further selection assistance, as well. DuPont, for instance, provides a tool called SafeSPEC, which helps users make informed decisions about chemical-protective apparel choices. The tool, available both online and as a mobile app, allows users to input specific hazard scenarios and yield best match results, and provides regular product updates and recommendations for a range of hazard scenarios. "It is a great resource because it takes into account the user's specific chemical, exposure, flame risk, and so on, and gives a set of products that can be considered for that exact application," explains Domnisch. "It lists all the product data, permeation data, literature and more to help the end user make the right decision in what can be a confusing myriad of standards and requirements."

And often industry experts are available to help, as well. Sally J. Smart, a Certified Safety Professional and technical safety specialist with Grainger (Lake Forest, Ill.; www.grainger.com), adds: "At Grainger, we value our conversations with our customers and strive to talk to them about all the considerations in fabrics and suits, as well as the design of the clothing. There's a lot to consider when selecting the suits, garments and equipment that are best for their needs without going overboard. We want to help them find that sweet spot, where the equipment is just enough to get the job done properly and safely without going overboard. We can help them find that once we have discussed their applications, chemicals, hazards and other factors."

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nisch, global marketing manager for Tyvek protective products with DuPont (Wilmington, Del.; www.dupont.com). "So industry is asking the question, 'Instead of having someone wear two different apparel offerings, how do we combine the two needs into a single product that is more comfortable, easier to wear and work compliant?'"

Answering that question has resulted in several new products from a range of manufacturers. DuPont offers Tychem ThermoPro (Figure 1), which offers triple-hazard protection from liquid chemical splash, flash fire and electric arc. Tychem ThermoPro coveralls combine the chemical protection of Tychem fabric and flame protection of Nomex fibers in a single-layer garment to provide at least 30 minutes of protection against over 180 chemical challenges, plus the added benefit of electric arc and flash-fire burn injury protection.

Similarly, Lakeland Industries (Ronkonkoma, N.Y.; www.lakeland.

Ansell

FIGURE 2. Microchem by AlphaTec 68-4000 from Ansell is a heavy-duty hazmat suit designed to provide multi-layer barrier protection against organic and inorganic chemicals and biological agents

com) offers its Pyrolon CRFR disposable, chemical-resistant and flame-resistant protective fabric. Garments made with Pyrolon CRFR prevent contaminating flammables like paint, oil and grease, hazardous liquids and contaminants and dry particulate matter from penetrating inner clothing and provide light-chemical splash protection. They are self extinguishing and won't melt or drip. However, they should be worn over primary fire-resistant clothing in environments where flash fire is a concern. "Most other chemical fabrics aren't flame resistant and are made of plastics, so if you expose them to flame they will burn and melt like a candle," says Kyle Kerbow, director of product management with Lakeland Industries. "Pyrolon CRFR is a spun-lace substrate that is flame resistant with a proprietary film on the outside so you have flame resistance built into your chemical suit."

Another multi-tasker, DuPont's Tyvek 500 HV garments combine chemical, biological and antistatic protection with the highest class of high visibility. (This product is currently available only in Europe.) "This combines chemical protection and high visibility into a single garment so workers who need to be seen don't have to wear a separate, reusable, high-visibility vest or other garment," says Domnisch.

Brass Knuckle Safety Products

FIGURE 3. N-FOG and N-FOG Plus anti-fog lens coating, used on Brass Knuckle's Snap and Mega protective eyewear lines, is tested to European antifog standards

Chemical gloves are no exception when it comes to multi-tasking. Magid Glove (Romeoville, Ill.; www.magidglove.com) currently offers a triple-polymer glove made of a blend of nitrile, neoprene and latex so that it can be used in many aggressive chemical applications, allowing processors to provide one glove for a myriad of applications. In addition, the company is working on chemical-resistant gloves that are also cut resistant. "This is a real challenge," explains Jim Kraft, health and safety technical specialist with Magid. "Traditionally, if you nick or damage a chemical-resistant glove with a cut-resistant liner, you run the risk of chemical getting through the glove and liner. We are currently testing a glove that puts the cut protection on the outside of a nitrile material glove so the cut protection is on the outside of the glove with the chemical resistance beneath it."

Worker comfort

Worker comfort is another trend, and for good reason, according to the experts. "Anytime we can provide a higher level of protection with enhanced comfort that makes a garment or piece of equipment less cumbersome, faster to don or easier to use, the more likely it is that workers will be compliant," says Dominisch. "It's a win for the worker and the employer when we can make PPE more protective and more comfortable."

When it comes to CPC, the experts at Ansell (Iselin, N.J.; www.ansell.com) focus on features and details that make their chemical protective suits safer and more user friendly. For example, Microchem by AlphaTec 68-4000 (Figure 2) is a heavy-duty hazmat suit designed to provide multi-layer barrier protection against organic and inorganic chemicals and biological agents. It offers a double-zip system and a double-cuff design to ensure tight seals that increase chemical protection, even if workers are moving around, lifting their hands and squatting down. In addition, says Dana Hammer-Fritzinger, senior global product manager for protective clothing with Ansell, the company offers other worker comfort features, such as a hands-free visor light system for its Trellchem suits. The short-throw illumination system is designed to offer improved visibility and a safer working environment via panoramic lighting that spreads light through a wide area with no risk of blinding reflections. "The LED visor light enhances visibility of the surroundings, allowing workers to do their job faster and safer," she says.

Another area of concern in the chemical process industries (CPI) is fogging of eyewear, so anti-fog glasses and goggles are currently a large worker comfort and safety issue. However, what you see is not always what you get, warns Tony Spearing, vice president with Brass Knuckle Safety Products (Alpharetta, Ga.; www.brassknuckleprotection.com). "For any worker in any environment, one of the most important things is that an employee wears eyewear that provides clear vision at all times. But the challenge with anti-fog eyewear in the U.S. is that there is currently no anti-fog standard for safety glasses. So, when you purchase safety eyewear marketed as having anti-fog properties, some can perform well and others, not so well."

He says that there is a European standard, EN 166/168, and some companies, such as his own, test safety eyewear against this standard. "Our N-FOG and N-FOG Plus anti-fog lens coating is tested to this standard and the duration to which our products perform against the standard is from 1,500 to 4,300% longer than what is dictated," says

FIGURE 4. Abom's safety goggles feature inner lens surfaces that are scratch-coated and have a transparent, thin-film conductive layer through which a small current is introduced and produces enough heat to clear up fog in a matter of seconds

Spearing (Figure 3). It is available on the company's Snap and Mega protective eyewear lines.

Similarly, Abom, Inc. (Portland, Ore.; www.abom.com) has introduced safety goggles featuring KLAIR technology to prevent fogging (Figure 4). However, this is not a coating. With KLAIR, the inner lens surfaces are scratch-coated on a dense polycarbonate lens to reduce or eliminate scratches from normal use and cleaning and then, using a transparent, thin-film conductive layer, a small current is introduced into the lens. This produces enough heat to clear up fog in a matter of seconds. "Powered by two lithium batteries, these safety goggles are rechargeable with a standard micro-USB cord or with a standard wall charger," says Jack Cornelius, Abom CEO. "These aren't inexpensive, disposable goggles, but they will ensure that your workers keep their goggles on because with the press of a button, they will be fog-free for an entire work day."

"Chemical workers face very dynamic challenges in their workplaces, so as manufacturers of protective gear, it is our goal to bring innovative solutions that allow them to do their jobs safely and effectively and return home to their families every night," says Domnisch. And, it would appear that PPE manufacturers are striving to provide garments, gloves and eyewear that will help ensure safety in the harshest of environments. ■

Joy LePree

Packaging

A&D Inspection

Bosch Packaging Technology

SP Industries

Machine secures complex loads to ensure safe transport

The Multi FleXL stretch hood machine is designed to secure and maintain the integrity of tall and wide pallet loads throughout the supply chain. With larger loads, proper load containment can be a challenge, and selecting the right type, size and thickness of stretch hood film and applying it appropriately is critical to ensuring the load will withstand the static and dynamic forces caused by handling, impact and vibration during transit, at all points throughout the supply chain. The machine wraps loads from 500 × 500 mm, and up to 3,200 mm length × 1,700 mm width, with a maximum height of 3,000 mm. It can be configured with up to four different film sizes, and be set up to automatically switch among them, to provide enhanced flexibility and a perfect fit for every load. Wrapping up to 150 loads per hour depending on the size and height of the product, Multi FleXL further provides fast and accurate results. — *Lachenmeier, Chicago, Ill.*
www.lachenmeier.com

Food-packaging materials can handle hot or cold contents

This company's new NX UltraClear polypropylene (PP) food packaging designs provide glass-like clarity to optimize the appeal of food, and heat resistance for hot-fill applications, warming under heat lamps and microwaving for reheating. The abiity for food packaging to be made from NX UltraClear PP streamlines inventory management and conserves storage space for users, says the company. — *Milliken & Co., Spartanburg, S.C.*
www.millikenchemical.com

Machine verifies the weight of packages in realtime

The Checkweigher (photo) is available to safeguard against underweight and overweight packages. It features a relatively small footprint, making the machine easier to integrate into an existing manufacturing process. It has a production rate of up to 400 pieces per minute. The machine features a newly desined digital load cell and a high-speed processing module, allowing it to deliver an unmatched level of precision weighing and measurement at ±0.8 g, says the company. Standard digital inputs and outputs, and a touch-panel color LCD screen make it user friendly. Dual-channel airjet ejectors allow the user to sort overweight and underweight products. — *A&D Inspection, San Jose, Calif.*
www.andinspection.com

Cartoning machine allows for quick changeover

This company has added the Sigpack TTMP, a new topload cartoner, to its TTM product portfolio (photo). The TTM platform is well-suited for the packaging of ampoules, vials, syringes, pens and further products from the pharmaceutical industry. The machine features a patented changeover concept that is both simple and safe, and ensures high process safety and broad product flexibility, says the company. Due to its modular design, the machine layout can be adjusted to different product needs. With an output from 30 to 200 cartons, the TTMP is well-suited for both large and small batches. Modules for forming and inserting partitioners, package inserts and tray de-nesting can also be integrated. — *Bosch Packaging Technology, Waiblingen, Germany*
www.bosch.com

Box dumper is customizable for a range of uses

The Rolo Box Dumper (photo) is a heavy-capacity production dumper with a dump angle of 135 deg, which is ideal for carts, bins and cans, scrap metals, metal chips, corrugated materials and more. Materials can be emptied from the Rolo Box Dumper directly into production units, sorting trays, tables, conveyors and smaller containers. A variety of custom at-

Note: For more information, circle the 3-digit number on p. 62, or use the website designation.

tachments and scoops can be built to match specific carts and containers. Additional options include PLC controls, hydraulic lock systems for carts, thermo oil heater, side-entry scoop and dumper enclosures. The dumper has a structural steel frame and high-tensile steel pivot shaft for durability and stability. This machine has a maximum dump height of 84 in. and a maximum capacity of 8,000 lb.— *SP Industries, Hopkins, Mich.*
www.sp-industries.com

New adhesive enables labels with reduced weight and waste

The patented Tego RC adhesives are ultraviolet-curing silicones that perform as release coatings for self-adhesive labels, providing a more environmentally friendly, linerless alternative to traditional labels (photo). By eliminating the need for a traditional peel-off release liner (the part of a traditional label that is discarded and typically makes up 40% of the weight of a label), this product helps to conserve resources and reduce material costs. Using Tego RC silicones, linerless labels can be rolled up without sticking to one another, says the company. These silicones are set and cured not using heat, as is the case of conventional self-adhesive systems, but rather using ultraviolet (UV) radiation in a fraction of a second, which helps to reduce energy consumption and conserve the label materials required, in applications related to food packaging and labeling of products for use during transportation and logisics management. — *Evonik Industries AG, Essen, Germany*
www.evonik.com

Packaging reduces exposure to moisture and oxygen

The Duma Twist-Off Protect is a multilayer plastic container (photo) that is said to have improved barrier properties to protect the package contents against degradation that can happen as a result of moisture vapor and oxygen permeability. It is the first plastic container with a multilayer structure manufactured in an injection blow-molding process, says the manufacturer. U.S. Pharmacopeia and ASTM F 1307 test data confirm that the container admits far lower levels of vapor and oxygen than other standard solutions on the market, says the manufacturer. Compared to extrusion blow-molded containers, it provides extremely good barrier properties due to better control of geometry and thickness.— *Gerresheimer, Düsseldorf, Germany*
www.gerrescheimer.com

Hoist expands capabilities of this bulk bag discharger

The customized Spider-Lift bag lifting frame (photo) has a patented design that uses 4-×-6-in. square steel structural tube main frame. The unit features an electric chain hoist with ground-level pendant control and a Spider-Lift bag-lifting frame. The system includes the company's Flo-Master bulk bag massaging system to promote material flow, and a stainless-steel Seal-Master round bag spout access chamber and custom stainless steel discharge transition. The unit features a pneumatic slide gate and a volumetric feeder for accurate feeding of materials into the process. A stainless-steel pneumatic bag spout-clamping system for dust-tight discharge is also included.— *Material Transfer, Allegan, Mich.*
www.materialtransfer.com

Gain better control of loading and unloading operations

The P3 All-Around Spring Level Loader (photo) uses a series of springs to improve the efficiency of pallet loading and unloading operations. A system of heavy-duty springs automatically lowers or raises a pallet as weight is added or removed. By doing so, the P3 Spring Level Loader maintains the top layer of boxes at an easy-to-access position. A turnable ring on the top of the unit allows the user to rotate the load so he or she can remain in the same position throughout the loading or unloading process, eliminating the need to walk around the pallet. A compact base design allows workers unubstructed access to loads. All of the P3 Spring components fit within the diameter of the turntable ring, so the worker can stand close to the unit at any position around the ring. The P3 Spring can accommodate loads from 400 to 4,500 lb.— *Presto Lifts, Inc., Norton, Mass.*
www.prestolifts.com ■

Suzanne Shelley

Evonik Industries AG

Gerresheimer

Material Transfer

Presto Lifts

Schneider Electric

Alicat Scientific

Omega Engineering

BPS

Magnetic flowmeters with several mounting options

With a wide range of flowtube sizes and an array of available transmitter configurations, the MagPLUS family of magnetic flowmeters (photo) offers precise, bi-directional metering of many types of fluids, from beverages and processed foods to potable water, industrial water and wastewater. The flowmeters feature fully welded construction, a selection of global standard flanges and end connections, rugged liners suited to all water and wastewater applications or hygienic sanitary design, as well as durable exteriors that are appropriate for underground installation and constant flooding. Thanks to a virtual grounding feature, this flowmeter eliminates the need for grounding electrodes or rings, reducing installation complexity and cost, while increasing long-term process reliability. A selection of three housing versions enables users to mount transmitters directly to the flowtube at 0- or 45-deg angles, or remotely in wall- or field-mount configurations. — *Schneider Electric, Palatine, Ill.*

www.schneider-electric.com

Small-footprint, fast-response mass-flow controllers

The Basis line of mass-flow controllers has been expanded to include the new 20SLPM model (photo). Specifically designed for original equipment manufacture (OEM) and process integration, this small-footprint instrument provides fast, accurate control of gas flowrates in a wide range of applications, including sparging into liquids and sample dilution, as well as many gas-mixing applications. Suitable for use in OEM gas analyzers, automated gas mixing on process lines and anywhere basic mass-flow-only control is required, a 100-ms control response enables Basis controllers to react in realtime to upstream fluctuations. Basis controllers are available with the following multi-gas calibrations: air, argon, CO_2, N_2, O_2 and N_2O (selectable over serial connection). Furthermore, helium and hydrogen are also available in single-gas units. — *Alicat Scientific, Tucson, Ariz.*

www.alicat.com

A customizable smart display for all types of process monitoring

Available in three screen sizes, the OM-SGD Series of panel meters (photo) offers a wide operating power-supply voltage range of 4 to 30 V d.c. and two alarm outputs. Waterproof NEMA 6 (IP67) versions are also available. Using the provided configuration software, users can select from over 40 standard display configurations to quickly program exact process requirements. Furthermore, users have the ability to customize colors, text labels, input scaling and units before uploading the selected display configuration to the meter via a USB interface. The OM-SGD is suitable for process monitoring in a wide range of industrial or laboratory applications in the chemical, water, petroleum, HVAC, electronics and semiconductor industries. — *Omega Engineering Inc., Stamford, Conn.*

www.omega.com

Unload 4,000-lb bulk bags with this heavy-duty discharger

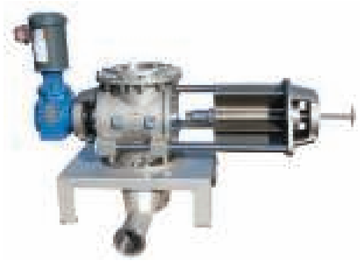
The Model MTD-4K bulk-bag discharger (photo) is designed for the reliable unloading of large-capacity bulk bags. With the use of 4-in. tubular construction, the machine can unload bulk bags with capacity up to 4,000 lb. A smaller model, the MTD-2.5K can unload bulk bags up to 2,500 lb. A heavy-duty version, the Model MTD BBD-4K, features vibratory-motor agitation to assist in unloading hard-to-remove products. — *Best Process Solutions, Inc. (BPS), Brunswick, Ohio*

www.bpsvibes.com

This airlock unit is suited for sanitary applications

The new Global Cleanable Airlock (GCA; photo, p. 29) is designed for applications where dry raw or finished products are being handled at high process rates, and where inspection or system clean-out are required. Available as either a standard or demountable unit, the GCA also possesses a number of features suited for sanitary processes. The standard model incorporates seals and product-contact surfaces that meet food safety requirements. The demount-

able unit is designed with a rail system that simplifies removal of the endplate and rotor assembly from the housing, providing access to the internal valve cavity, rotor pockets and all other product contact areas for quick and easy cleaning. GCA units feature stainless-steel construction and housing and endplates designed for explosion and shock resistance. An oversized rotor shaft creates a naturally radiused rotor pocket for more complete product release — *Schenck Process LLC, Whitewater, Wis.*
www.schenckprocess.us


Schenck Process

Security features are built into this controller

The new Allen-Bradley CompactLogix 5380 controller (photo) provides up to 20% more application capacity than previous CompactLogix versions. This controller is particularly helpful for high-speed packaging applications where fast response times are critical, says the manufacturer. Features such as scheduled outputs and event triggers allow engineers to design compact machines that achieve higher accuracy and precision. Diagnostic indicator lights display the status of communications, module health and I/O module activity. This allows operators and technicians to immediately understand problems without connecting the controller to a computer. In addition, built-in system and field power terminals reduce wiring to I/O modules. The controller also incorporates security technologies and software features, including digitally signed and encrypted firmware, controller-based change detection and audit logging. — *Rockwell Automation, Milwaukee, Wis.*
www.rockwellautomation.com


Rockwell Automation

This device monitors hazardous gases in compressed air

ProAir 2200 (photo) is a compact compressed-air line monitor that can continuously and simultaneously monitor up to four gases in realtime using internally mounted sensors. ProAir 2200 can be custom configured to monitor a variety of hazardous gases present in compressed air, including CO, CO_2, volatile organic compounds (VOCs), trace hydrocarbons and many other gases associated with OSHA monitoring requirements for Grade D breathing air. The monitor can be adapted to meet specific industrial requirements for compressed-air line monitoring. — *Enmet Corp., Ann Arbor, Mich.*
www.enmet.com


Enmet

Measure propylene glycol content in water with these test strips

WaterWorks Propylene Glycol Check is said to be the world's first visual test strip that measures propylene glycol levels. With simpler operations than a refractometer, the strip verifies that fluids are in good working order to prevent damage to cooling systems. The strips can test for levels in water from 20–60%. Test strips only need to be dipped in water for 2 s to conduct a check. After dipping the strip, users can determine the propylene glycol levels after just 60 s. The strip will change colors, indicating its status. The strip's color is then matched to an included color chart. — *Industrial Test Systems (ITS), Inc., Rock Hill, S.C.*
www.sensafe.com

Four new sizes added to this range of condensing boilers

This company has added four additional sizes to the Arctic Series of condensing boilers (photo). The new models range from 1.5 to 3 million Btu with certified efficiencies of 95%. The stainless-steel boilers feature a non-welded heat exchanger. Arctic boilers are available in fully packed or knock-down configurations, allowing them to fit into spaces where other condensers are not easily installed. An Arctic boiler accommodates variable primary and secondary piping designs due to minimal waterside pressure drops and low minimum flows. A 5:1 burner turndown is standard, with a 20:1 option to be available later this year. — *Thermal Solutions LLC, Lancaster, Pa.*
www.thermalsolutions.com


Thermal Solutions

This laboratory bead mill is robust and reliable

The new Dispermat SL-B horizontal bean mill (photo, p. 30) is suitable for fine grinding batch sizes from 150 to 750 mL, and features an integrated mill-base circulation system, which means there are no external pumps to clean. The speed control is infinitely adjustable from 0 to 6,000 rpm. This new model utilizes an integrated pneu-

Fullbrook Systems

Piab

Eisele Pneumtics

Alfa Laval

Hoerbiger Safety Solutions

matic press-out system, whereby the mill base is pressed out to ensure that the dispersed product can be almost completely regained with minimal wastage. The product sample is conveyed through the horizontal milling chamber with minimal clearance volume by a spiral conveyor, which is connected to the milling rotor, while the separation of the mill base is made by a dynamic gap. The mill features a wear-resistant stainless-steel milling chamber and a milling rotor made of hardened nitride steel. Shaft sealing is provided by a mechanical seal with integrated pressure system and cooling. An explosion-proof, ATEX-approved version is also available. — *Fullbrook Systems Ltd., Hemel Hempstead, U.K.*
www.fullbrooksytems.com

New online configuration tool for ATEX conveyors

Until now, ATEX gas-and-dust certified versions of this company's vacuum conveyors were only available by special order. Now, users can visit the company's website and configure the most suitable version of its piFLOWp (photo) or piFLOWt conveyors online. With these ATEX-certified conveyors, all plastic and rubber parts — including the filters and seals used between sheet-metal parts — are made of dissipative (antistatic) materials. All complete modules or units are fitted with seals of synthetic rubber (nitrile butadiene rubber), which have antistatic properties. Over 300 different configuration options for complete conveyors are possible. — *Piab AB, Täby, Sweden*
www.piab.com

The first tube connection with a consistent hygienic design

The new stainless-steel connector of the CleanLine series (photo) fulfills all of the important criteria for use in the food processing industry, and is constructed entirely according to the regulations of the European Hygienic Engineering & Design Group (EHEDG). On the outside and top, it is completely sealed by FDA-compliant seals made of ethylene propylene diene monomer (EPDM). The outer contour is rounded and micro-machined to minimal roughness (Ra <0.8 µm) to prevent any accumulation of impurities and also to facilitate cleaning of the connection. The same applies to the inside of the connection, which is manufactured from stainless steel 1.4404. It is completely free of dead zones and can be cleaned simply by flushing. The inside is hermetically sealed by two seals so that no liquid can penetrate the connector from outside. — *Eisele Pneumtics GmbH & Co. KG, Waiblingen, Germany*
www.eisele.eu

Heat exchangers for demanding hygienic applications

With a design pressure of up to 21 bars (305 psi), the FrontLine gasketed plate heat exchanger (photo) allows a flexible design with plates tailor-made for demanding hygienic applications. The plate pattern, the channel depth and the overall dimensions are designed for gentle, uniform heat transfer for sensitive dairy, food, beverage and personal-care products. The FrontLine can be configured with different sections, using plate and gaskets in different materials with several types of connections making the final unit suited to users' specific processing tasks. A unique herringbone plate pattern with optimized pressing depth and plate material provides gentle, uniform heat transfer of sensitive hygienic products. FrontLine is also designed with a wide stream plate for product containing particles or fibers, such as fruit juices. — *Alfa Laval Lund AB, Lund, Sweden*
www.alfalaval.com

Lowering operating costs with active grounding protection

To ground and monitor multiple pieces of equipment, such as loading and mixing stations for tanks or railway cars, a large number of conventional static ground systems would normally be required to provide adequate protection against incendive electrostatic sparks. In addition to these flammable liquid and gas applications, powder processing equipment, such as fluid-bed dryers and micronizers, typically require multiple grounding systems to adequately protect potentially explosive dust atmospheres. The Earth-Rite Multipoint II (photo) allows up to eight individual pieces of equipment

to be monitored with a single system. It consists of a compact and well-organized monitoring and control unit with LED display. In addition, optional remote-indicator stations may be specified for the process environment. Since the remote indicator stations are supplied via the intrinsically safe circuits of the monitoring and control unit, no additional external power supply is needed. — *Hoerbiger Safety Solutions, Vienna, Austria*
www.hoerbiger.com

A new high-pressure combination air valve

The new high-pressure combination air valve, the ASU-CAV (photo) is a single body, combination automatic air valve featuring an innovative design for clean or dirty service applications in mining, petrochemicals, water treatment, reverse osmosis and high-pressure (150–300 psi) wastewater. Available in sizes 1 to 4 in. with all stainless-steel construction, the new valve provides maximum corrosion resistance. The lightweight, low-profile design also operates without linkages to assure proper operation and increased durability, and meets AWWA C512 requirements. — *DeZurik, Inc., Sartell, Minn.*
www.dezurik.com

DeZurik

Bluetooth for level and pressure transmitters

This level and pressure instrumentation specialist has brought a Bluetooth solution to the market (photo). A new generation of the universal display and adjustment module plicscom will allow all the transmitters in the plics instrument platform to be remotely operated via an app — easily, conveniently and securely — thereby enhancing the concept of the modular instrument platform plics. Its wireless Bluetooth communication is suitable for all industries and is particularly suited for applications in difficult-to-access locations, harsh industrial environments and hazardous Ex areas. The new module is backward compatible, which means it can be used on the entire installed base of more than 1.5 million plics sensors, many in operation since 2002. — *Vega Grieshaber KG, Schiltach, Germany*
www.vega.com

Vega Grieshaber

Dissolved-air flotation optimized for exhaust-air treatment cycles

Traditional dissolved-air flotation systems produce the flotation motive water through air saturation of a partial flow in the plant outflow. The saturation usually takes place using multi-stage pumps, which only run smoothly if they are fed with pH-neutral wastewater that is mostly free from solids. The injector system developed by this company achieves micro-bubble formation comparable to saturation by pumps. The air saturation of the partial flow is carried out by an injector pressure container, which is fed by a wastewater pump resistant to solids and which can handle both alkaline and acidic wastewater without any problems. This enables cycles to be driven through flotation systems without chemical conditioning or neutralization. The flocculant dosage is required only to produce separable flocs. If floating solids are present without flocculation, a chemical-free procedure is possible. — *EnviroChemie GmbH, Rossdorf, Germany*
www.envirochemie.com

New high-density cable entry solutions

This cable- and pipe-transit provider has introduced a high density (HD) cable-entry device for use in terminal boxes and enclosures (photo). The HD cable entry system meets challenges with high cable density in applications with that demand the utmost in safety, and is available in versions for use in potentially explosive atmospheres, as well as for non-hazardous locations. Besides providing environmental protection, it helps designers and installers save time, space and money. The cable entry device consists of an AISI 316L acid-proof stainless-steel frame and industry-proven components, such as sealing modules, making it adaptable to cables of different sizes. A single cut-out for the HD kit can accommodate up to 32 cables, which reduces the amount of space required when compared to 32 traditional cable glands. Designers and manufacturers cut weight by half and increase cable capacity by up to 40% when compared to cable glands, says the company. — *Roxtec International AB, Karlskrona, Sweden*
www.roxtec.com ■

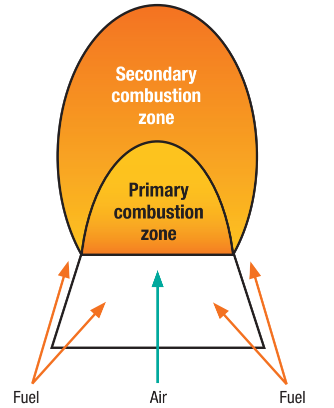
Mary Page Bailey and Gerald Ondrey

Roxtec International

Industrial Gas Burners

Department Editor: Scott Jenkins

Combustion in industrial burners is a critical operation in the chemical process industries (CPI) for supplying thermal energy for heat transfer, fluid heating, steam generation, distillation, endothermic chemical reactions, metal melting and others. Burners are mechanical devices utilized for mixing proper quantities of fuel and air, and also for maintaining a stable flame inside fired equipment. Included here are brief descriptions of key aspects of industrial burner components and operation.



Fuel-air mix

Industrial process burners can be classified in several ways, including the type of fuel-air mixing involved (diffusion or premixing).

Raw-gas burners are used for most applications. In these burners, the fuel gas passes through orifices in the gas tip and is injected directly into the combustion zone, where it mixes with air. A stabilizer cone is located just below the gas to improve combustion stability. These burners are suitable for mounting in plenum chambers (the area where air enters the burner), and can be used with preheated combustion air.

Pre-mix burners are those in which fuel and air are mixed prior to combustion. Pre-mix burners are sometimes used in specialized applications. In these burners, the kinetic energy made available by the expansion of the fuel gas through the fuel-gas orifice introduces about half of the combustion air (called primary air) into the Venturi mixer. This mixture then exits through a large burner tip, where it is mixed with the balance of the combustion air (secondary air). This secondary airflow enters the burner through the outer, secondary air register. Premix burners require less furnace draft than raw-gas burners. Premix burners can produce a wide range of flame shapes.

Reducing NOx

Combustion operations frequently create nitrogen oxides (NOx), specifically NO and NO_2, which must be highly controlled, as they can be harmful pollutants. Currently, three burner configuration methods exist for reducing nitrogen oxides in burners: staged air, staged fuel and internal fluegas recirculation combined with staged air or staged fuel.

Staged air burners. These types of burners work by introducing 100% of the fuel into the burner and only part of the combustion air (primary air), thus creating a sub-stoichiometric flame. This flame has a reduced temperature and therefore inhibits NOx formation. The flame is completed with the addition of the secondary air to complete the combustion process. This process allows for greater control at lower burner loads and also accommodates a wider range of fuels.

Staged fuel burners. This burner method introduces 100% of the combustion air into the burner and splits the fuel supply into primary and secondary volumes (Figure). The primary fuel mixes with the combustion air to create a flame. As with staged air burners, the peak flame temperature is lower, and NOx formation is reduced. Secondary fuel is added to complete the combustion process. Staged fuel burners provide greater NOx reduction, as the fuel supply has a larger effect on NOx formation. This method is more commonly used when a consistent fuel supply is available.

Internal fluegas recirculation burners. This method combines either staged air or staged fuel with internal fluegas recirculation to help reduce NOx formation. The best results are obtained where internal fluegas recirculation is used to dilute the fuel gas in a staged fuel burner, creating a gas with a low calorific value.

Flame size

The size of the burner flame is an important parameter in controlling the heat transfer to tubes in the furnace. The flame size and shape should be such that the tubes impingement of the flame upon the tubes they are heating is avoided.

Maximum flame diameter can be calculated using Equation (1).

$$D_{f\,max} = \left(\frac{SV_{flame}}{SV_{fuel+air}} \right)^{0.5} D_b \qquad (1)$$

where:
$D_{f\,max}$ = Maximum flame dia., ft
L_f = Flame length, ft
SV_{flame} = Specific volume of flame, ft^3/lb
$SV_{fuel\,+\,air}$ = Specific volume of fuel and air mixture, ft^3/lb
V_f = Flame propagation velocity, ft/s

Maximum burner length can be calculated from Equation (2)

$$0.785 D_b^2 V_b = 3.14 \frac{D_b L_f V_f}{2} \qquad (2)$$

where:
D_b = Burner diameter, ft
V_b = Burner exit velocity, ft/s
The diameter of the burner flame should be evaluated at maximum burner-flame length.

Burner spacing

Burner spacing is normally 2 to 5 ft, or sufficient to provide reasonable burner-to-burner clearance, as based on the maximum burner-flame diameter. Burner-to-tube clearance must also be such that minimum clearance is based on a reasonable distance between burner outside-flame diameter and outside diameter of the tubular heating surfaces. ■

Editor's note: The content presented in this column was adapted from the following articles: Cross, Alan, Fired-Heater Burner Performance, *Chem. Eng.*, April 2008, pp. 44–47 and Al-Hajji, M.H., Burner Inspection and Maintenance, *Chem. Eng.*, November 2014, pp. 40–45.

LLPDE Production Using a Gas-Phase Process

By Intratec Solutions

Linear low-density polyethylene (LLDPE) is a copolymer of ethylene and longer-chain alpha-olefins, manufactured on commercial scale via low-pressure polymerization processes. The main technologies suitable for LLDPE production include slurry, solution and gas-phase processes. The most common co-monomers used commercially are 1-butene, 1-hexene, and 1-octene.

LLDPE is used in a broad range of applications due to its attractive mechanical properties and low cost. The greatest demand for LLDPE resins is associated with plastic film and sheet end-use, representing most of the total production. Compared to blown films of low-density polyethylene, LLDPE films exhibit tremendous toughness, dart impact and puncture resistance.

The process

The following paragraphs describe a gas-phase polymerization process for LLDPE production, using 1-butene as a co-monomer. Figure 1 presents a simplified flow diagram of the process, showing the main pieces of equipment. Examples of commercial gas-phase processes for LLDPE production similar to the one discussed here include: Univation Technologies' (Houston; www.univation.com) Unipol and Ineos Technologies' (Rolle, Switzerland; www.ineos.com) Innovene G.

Feed preparation and polymerization. Initially, raw materials are purified, since catalysts used in the process are sensitive to specific impurities. Such feed purification consists mainly of removing oxygen and water from ethylene and 1-butene, by means of purification columns and molecular sieves. After purification, the ethylene is polymerized in combination with 1-butene in a reaction loop consisting of a reactor, a compressor and a heat exchanger. The molecular weight of the polymer is controlled by the addition of hydrogen gas, while the polymerization rate is controlled by the catalyst feed rate. Polyethylene granules are removed from the reactor and directed to a purge bin downstream.

Polymer degassing and vent recovery. In the purge bin, residual hydrocarbons are stripped with nitrogen. The purged gas is sent to vent recovery, while the polymer powder is directed to the pelletizing and finishing section downstream. In the vent recovery, unreacted monomers are condensed and pumped back to the reactor, while the uncondensed gas is purged.

Pelletizing and finishing. The polymer powder from the purge bin is fed to a pelletizing system along with a mixture of additives. There, the mixture is melted, homogenized, and pelletized. Subsequently, the LLDPE pellets are packed in bags before being stored in warehouses.

Economic performance

An economic evaluation of the process described here was conducted based on data from the first quarter of 2014. The total capital investment estimated to construct an LLPDE plant with capacity to produce 450,000 metric ton per year of polymer in the U.S. is about $370 million. The capital investment includes fixed capital, working capital and additional capital requirements. The production costs (raw materials, utilities, fixed costs, corporate overhead and depreciation costs) are about $1,500 per ton of LLDPE produced. Figure 2 shows the production costs distribution.

This column is based on "LLDPE Production via Gas-Phase Process — Cost Analysis," a report from Intratec. It can be found at: www.intratec.us/analysis/lldpe-production-cost. ■

Edited by Scott Jenkins

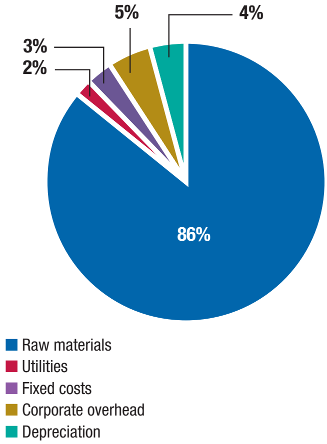


FIGURE 2. Raw materials account for most of the production costs for LLDPE

Editor's Note: The content for this column is supplied by Intratec Solutions LLC (Houston; www.intratec.us) and edited by *Chemical Engineering*. The analyses and models presented are prepared on the basis of publicly available and non-confidential information. The content represents the opinions of Intratec only. More information about the methodology for preparing analysis can be found, along with terms of use, at www.intratec.us/che.

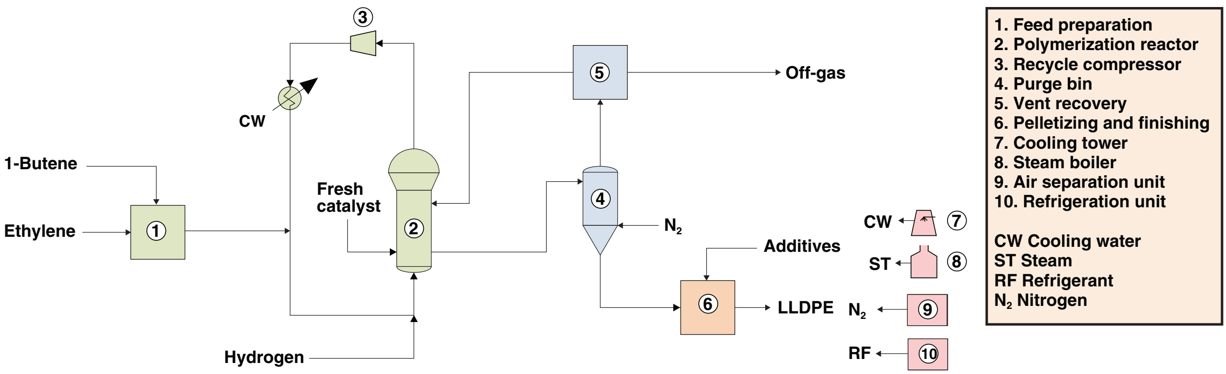


FIGURE 1. The process diagram shown here represents the production of LLDPE from ethylene and 1-butene via a gas-phase process

Cybersecurity Defense for Industrial Process-Control Systems

Security techniques widely used in information technology (IT) require special considerations to be useful in operational settings. Here are several that should get closer attention

Mike Baldi
Honeywell Process Solutions

IN BRIEF

CYBER THREATS AND CONSEQUENCES

DEFENSE IN DEPTH

ADAPTING TO THE NEEDS OF OPERATIONAL TECHNOLOGY

RISK-ANALYSIS SOLUTIONS

NEXT-GENERATION FIREWALLS

ENDPOINT PROTECTION

LOOKING TO THE FUTURE

Honeywell

FIGURE 1. Expansion of the Industrial Internet of Things (IIoT) and cloud storage offers benefits, but raises security concerns

Industrial cybersecurity risks are widely appreciated. In April, the deputy director of the U.S. National Security Agency, Rich Ledgett, warned that industrial control systems (ICS) and other critical infrastructure assets remain vulnerable to attack (Figure 1). Robust cyberdefense of industrial facilities remains an ongoing challenge for the chemical process industries (CPI). The convergence between the world of information technology (IT) and the world of operational technology, in which control systems for industrial facilities reside, has brought tremendous benefits, along with more complex security concerns. The same convergence, however, has allowed the industrial world to adopt cyberdefense techniques that have been widely used in IT. This article discusses several key cybersecurity IT tools that can help industrial facilities establish a layered cybersecurity system for its operations.

Cyber threats and consequences

The Stuxnet worm, a computer virus that infamously affected Iran's nuclear centrifuges, and the damage due to a cyberattack of a German steel mill reported in 2014 are evidence that cyberattacks can have physical, real-world impacts. But it is not necessary to prompt an explosion to cause significant disruption. A cyber attack on Ukraine's electric power grid, and subsequent widespread power failure last December, was evidence of that.

As NSA's Ledgett put it, "You don't need to cause physical harm to affect critical infrastructure assets."

Cybersecurity risks are not easily addressed, however. One challenge is the increasing sophistication of attacks. The German government report on the steel mill incident, for example, noted that the attackers demonstrated not only expertise in conventional IT security, "but also detailed technical knowledge of the industrial control systems and production processes used in the plant."

Moreover, once the tools and knowledge to enable such attacks are developed, they are often quickly commoditized and shared, allowing others with fewer technical skills to use them.

Another challenge, however, is simply the increasing vulnerabilities introduced by the growth of intelligent, connected devices in industrial control systems. As Chris Hankin, director of the Institute for Security Science and Technology (ISST) at Imperial College, London (www.imperial.ac.uk/security-institute), remarked recently: "Almost every component of such systems now has fully functional computing capability and most of the connections will now be Ethernet, Wi-Fi or will be using Internet protocol."

The growth of the Internet of Things — and, more specifically the Industrial Internet of Things (IIoT), in particular — is adding to both the number of devices and their connectivity. Today, the IT research and advisory company Gartner Inc. (Stamford, Conn.; www.gartner.com) estimates 6.4 billion connected devices are in use worldwide. By 2020, it forecasts, that total will reach 20.8 billion. Moreover, heavy industries such as utilities, oil and gas, and manufacturing are among the leading users. Each device and connection expands the possible attack surface for cyberattacks.

Closely connected to the increasing number of connected devices is the growth of the network of remote computer servers casually known as the "Cloud," which provides access to infinitely scalable computing power and storage. The Cloud provides an opportunity to store and process the large volumes of data resulting from the proliferation of connected devices, such as with the IIoT. Again, however, it introduces new connection and communication channels that would-be cyberattackers will try to exploit.

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FIGURE 2. A layered approach to cybersecurity, with several types of different cyberdefenses should be the objective of industrial control systems

Defense in depth

In fact, the security issues related to the IIoT and Cloud storage result from the longer-term challenges surrounding the convergence between the IT and operational technology (OT) worlds. Open platforms and the proliferation of third-party and open-source software in industrial control systems has long brought the power and efficiencies from the enterprise side of the business to the process side. But along with those benefits, the convergence also brings associated security concerns.

To complicate matters, while the vulnerabilities on both sides — enterprise and operations — may be similar, the solutions are often not directly transferable. The priorities of each are necessarily different: while confidentiality can be prioritized in the enterprise; availability and integrity must, for the most part, take priority on the OT side. In practice, a security solution cannot be allowed to shutdown operator access to data or devices that are essential to the safe running of the plant, even if the security of those data is at risk of being compromised.

ISST's Hankin acknowledged this reality in his speech: "While there has been a convergence between the two worlds [IT and OT], particularly in the past five years, there are major differences, such as the fact the industrial control systems (ICS) tend to have to operate in a time-critical way; they have to

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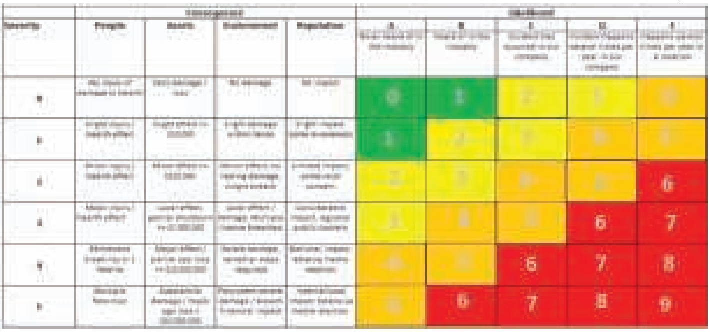

FIGURE 3. Risk analysis enables the prioritization of cybersecurity risks so that limited resources can be applied intelligently

operate around the clock; and edge clients, such as sensors and actuators, are becoming much more important" (Figure 2).

In essence, the options for ensuring security are more limited in the OT world. This is partly why the concept of "defense in depth" is so important to industrial security: without the option of configuring protection mechanisms to potentially inhibit system availability, it is even clearer in an OT setting that no single security solution can provide complete protection. A layered approach that employs several different defenses is the better goal. Such an approach means that if (or rather, when) one layer fails or is bypassed, another may block the attack. Defense in depth makes it more difficult to virtually break into a system, and, if it includes active monitoring and a good incidence-response plan, promotes quicker detection and responses that minimize the impact where an attack does breach security.

This also means that — perhaps even more so than in the IT world — security in an operational setting cannot rely solely on software. As in all operations, success is only achieved through a combination of people, processes and technology.

Adapting to the needs of OT

Notwithstanding these points, though, security developments in the IT world do prove valuable to operations. Provided the priorities of OT users are accommodated, and the solutions are implemented in an appropriate framework, recent IT developments offer significant potential to boost security in the OT world of industrial facilities.

Four recent technologies, in particular, are worth looking at in more detail:

- Risk-analysis technologies that enable plants to prioritize investments in cybersecurity
- Next-generation firewalls, which can bring about radical improvements in network protection
- Application whitelisting and device control to protect individual end nodes
- Advanced analytics, focused on using "big data" to detect and predict cyberattacks

The first three are already seeing significant uptake, and accompanying security benefits, among industrial users. The last offers a glimpse at how industrial cybersecurity is likely to continue to develop in the future, based on IT trends. It also demonstrates how the increasing connectivity and elastic computing power embodied by the IIoT and the Cloud can contribute to the security challenges they have done so much to highlight.

Risk analysis solutions

A key value of risk analysis is that it recognizes that resources are finite. Plant owners face numerous choices about where and how to apply security controls and solutions. Risk analysis techniques provide a way to quantify, and therefore prioritize, cybersecurity risks, to ensure that limited resources are applied effectively and efficiently to mitigate those that are most severe.

That quantification is aided by the existence of standard definitions of risk from bodies such as the International Organization for Standardization (ISO; Geneva, Switzerland; www.iso.org) and the National Institute of Standards and Technology (NIST; Gaithersburg, Md.; www.nist.gov). The former defines risk as "the potential that a given threat will exploit vulnerabilities of an asset or group of assets, and thereby cause harm to the organization." The latter characterizes risk as "a function of the likelihood of a given threat source's exercising a particular potential vulnerability, and the resulting impact of that adverse event on the organization."

Cybersecurity risk is therefore a function of vulnerabilities, threats and potential consequences of a successful compromise. By accepting this as a definition, risk can be quantified and prioritized.

In practice, vulnerabilities will always exist — whether in the form of a software bug or due to weak passwords or poor system configuration. They cannot be entirely eliminated. Threats, meanwhile, constantly vary, and will be driven not just by the availability of malicious software or technical knowledge, but also by the motivation and means of potential attackers. The consequences of exploiting a specific threat have to be calculated into a relative risk score for each vulnerability (Figure 3). Owner-operators of industrial control systems can then determine what level of risk to mitigate, and which risks they are willing to accept — their risk appetite.

Since vulnerabilities and threats continually evolve and expand (with 200,000 new variants of malware identified every day, for example), the process must be continuous. Automating the risk-analysis process brings significant benefits to the security of a plant.

Risk-analysis software does so, and enables users to monitor networks and system devices in realtime (Figure 4). By consolidating complex site-wide data, risk-analysis software significantly improves the ability to detect threats and identify vulnerabilities. Perhaps more importantly, by calculating the risk for each device in realtime, it enables prioritization of risks by their potential impact to the plant or business. It also provides a realtime update when the risks change due to new threats or vulnerabilities to the system. Combined with well-configured alerts, users can assign resources more efficiently, and respond more effectively and more quickly to risks.

In the IT world, risk-analysis and risk-management solutions have seen widespread uptake, but there are difficulties in simply transposing these to an industrial setting. First, the requirements and competencies of the users — control engineers and operators, as opposed to IT staff — are different. An OT risk-analysis tool must present results that are meaningful to non-security specialists who operate the ICS around the clock.

Second, allowance has to be made for the OT environment. Many traditional vulnerability assessment (VA) tools used in enterprise systems may be unsuitable (and possibly unsafe) when applied to network activity in an ICS.

This is because they probe aggressively to test for vulnerabilities, launching a variety of network packets directed at every possible port on an end node. The responses are used to determine the state of each port, and whether the protocols are actively supported. A database of known vulnerabilities is then used to match the responses, and then further scanning of the device is attempted.

There are two key problem areas with this technique.

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FIGURE 4. By compiling complex, site-wide data, risk-management software can improve the ability of plants to detect threats and identify vulnerabilties

- Non-standard network traffic into poorly managed ports can cause unintended consequences — including locking up a communications port, tying up resources on the end node, or even hanging up an entire end node. This type of probing can reveal weaknesses in the configuration or programming of applications that results in unintended consequences
- Network scanning can increase the load on an end node to an unmanageable level, resulting in a denial of service (with the node unable to complete normal operation), or even a node crash. To avoid this vulnerability, scanners must be "throttled" properly to protect both the end nodes as well as the network latency and bandwidth

An IT VA tool may therefore introduce risks to the safe operation of an ICS, as much as it may identify them.

Essentially, realtime risk analysis in an OT environment must be tailored to ensure that it never interferes with normal plant operation or control. It must also provide realtime, actionable information that can be used by operators, security administrators and business leaders.

VA tools tailored to the ICS environment are now becoming available, and are seeing good uptake. With the scale of the cybersecurity challenge continually growing, they are likely to become an increasingly important tool in helping operators focus and tailor their cybersecurity strategies.

Next-generation firewalls

In IT systems, firewalls are among the most widely used cybersecurity measures. While antivirus software protects the end nodes, the firewall monitors and controls network traffic based on configured security rules to detect and prevent network-based cyberattacks. For most business, they are the first line of defense in their cybersecurity strategy.

Next-generation firewalls (NGFWs) significantly enhance the protection capabilities of these systems. In addition to traditional network protection which restricts access to a particular port or address, NGFWs include deep packet inspection of network traffic in realtime.

Increased analysis of the content of network traffic (not just the source and destination addresses) facilitates a range of additional defenses:

- Application profiling — tracking application behavior to raise alerts or interrupt communications displaying abnormal behavior, or patterns associated with known malware
- Protocol support — including, in industrial NGFWs and most industrial control system protocols, such as Modbus, DNP3, OPC and HART. This allows the NGFW to be configured to restrict protocols to only specific functions, such as restricting the ability of applications using Modbus to write to certain registers, or restricting all write commands coming into the ICS
- Potential to interface with the ICS domain controller to identify the user associated with specific application traffic on the plant control network and to block unauthorized users
- Advanced threat detection (on high-end NGFW), based on network traffic patterns, and signatures of known malware

The potential benefits of NGFWs may even be greater in an OT than IT setting. Network traffic in the OT environment is typically more "predictable," with most communication channels clearly defined. That makes it possible in many cases to more tightly lock down communications traffic on an ICS — and easier to determine deviations from normal network traffic patterns.

Again, there are significant challenges, though: an NGFW can decode some, but not all, encrypted traffic, for example. ICS owners also need to coordinate the NGFW selection with their process control vendors to ensure the correct configuration and to ensure that network performance is not affected when on critical operations and network traffic latency.

However, the potential rewards make this worthwhile. An NGFW not only provides tighter control of network traffic, but more intelligent control: it is as much about letting desirable traffic through as detecting and blocking threats.

More highly sophisticated control gives plant operators not only increased protection, but also the confidence to allow connections they would otherwise feel forced to block: to enable and control access for an increasing range of applications; to facilitate authorized personnel using mobile devices; and to promote collaboration across the enterprise with controlled access to realtime data.

End-point protection

Application whitelisting (AWL) is another staple in traditional cybersecurity approaches. It protects individual end nodes by restricting the files that can be executed to only those specifically authorized to run.

Its value is well recognized. Whitelisting is listed first among the top four strategies listed by the Australian government intelligence agency, the Signals Directorate, and last October, NIST published a guide to whitelisting for businesses.

As the NIST guide notes, the power of application whitelisting comes from its prescriptiveness: "Unlike security technologies, such as antivirus software, which block known bad activity and permit all other, application whitelisting technologies are designed to permit known good activity and block all other."

Added to this, whitelisting avoids some of the maintenance required for technologies like antivirus software or intrusion prevention/detection systems (IPS or IDS). Such "blacklisting" technologies require frequent updates to the "known bad" signatures; DAT files (binary data files with .dat filenames) for antivirus solutions are updated daily with new "known malware" signatures. More sophisticated malware, meanwhile, is being designed to evade detection by signature-based security protections.

Application whitelisting therefore represents a strong additional line of defense against malware that is designed to add new software or modify existing software on an end-node. It can also offer some protection for obsolete operating systems no longer supported by new security patches (such as Windows Server 2003 and Windows XP operating systems).

There are challenges for an ICS, however. Whitelisting takes time to set up and configure in all systems. The difficulty lies in ensuring that all applications that need to be run on a particular node are enbled (or not blocked). In an ICS, the risks of blocking or impacting normal operations are often greater, however. If improperly configured, a whitelisting solution can prevent normal operations, causing operators to lose visibility or control of the plant. It must therefore be tightly integrated into the control system operation, because it is active before every file execution on the system.

To minimize the risk, the AWL solution should be fully qualified by the ICS vendor or end user before use. Most solutions also offer various operation modes: monitoring or observation, in which users can monitor unauthorized file execution without blocking any operations; "self approval" — in which message pop-ups enable users to override any blocked executable; and full implementation in which whitelisting policies are fully executed and enforced. The last should only be used after the site has validated the whitelisting configuration against all normal plant usage scenarios.

Where this is done, however, whitelisting has proven an effective and safe solution in industrial settings, bringing similar benefits for cybersecurity that have been realized in the IT world. In addition to managing executable files, whitelisting solutions increasingly offer a wide range of functionality:

- Managing USB (universal serial bus) and removable storage devices, allowing users to restrict USB device usage by vendor, serial number or function (restricting to read-only, for example)
- Extending device management capability to control wireless, Bluetooth and all plug-and-play devices on the system
- Protecting access to the local registry
- Managing access to non-executable files
- Protecting against malicious behavior of programs in memory (such as buffer overflows)
- Controlling execution of scripts or activeX controls
- Executing files with reputation-based decisions
- Tracking processes changing files on the system

Like NGFWs, application whitelisting is a mature technology and integral part of most IT cybersecurity strategies. Increasingly, the same is becoming true in the OT space.

Looking to the future

Advanced analytics, by contrast, remains resolutely immature in the industrial environment. It is, however, an important emerging technology that once again offers significant potential for OT systems.

While the value of risk analysis is that it recognizes resources for cybersecurity are finite, the value of advanced analytics is that it accepts that complete security is unachievable. With the threat landscape constantly evolving, it is impossible to completely mitigate all threats to the ICS.

Those that have the potential to do the most harm will be those threats of which organizations remain unaware. The faster plants can detect malicious actors on the system or network, the faster they can address them and minimize the damage.

Advanced analytics uses big data tools to monitor and analyze a whole range of information sources, from email and social media, to network flows and third-party threat feeds. With this information, it can identify abnormal patterns that indicate attacks or intrusions. Not only can advanced analytic techniques detect recognized threats, but they can also allow the ability to predict new, emerging dangers. Such systems, for example, can automatically notify users of a cyberattack occurring on a related system elsewhere in the world — in realtime — enabling them to take precautions to protect their own sites.

While advanced analytics are increasingly important in cybersecurity, there is little uptake to date in the OT world. That, however, is likely to change — as it has with other key technologies in the IT realm. Convergence between IT and OT means the challenges facing the two are often similar. As long as industrial users pay due regard to the distinctive requirements of process control systems, there is no reason the solutions for OT cannot draw on the lessons that have been learned. In time, it may have insights to share with IT as well. ■

Edited by Scott Jenkins

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Editor's note: For more information on cybersecurity in the CPI, visit our website (www.chemengonline.com) and see articles by Andrew Ginter (*Chem. Eng.*, July 2013) and Eric C. Cosman (*Chem. Eng.*, June 2014).

Plant Functional Safety Requires IT Security

Cybersecurity is critical for plant safety. Principles developed for plant safety can be applied to the security of IT systems

Peter Sieber
HIMA Paul Hildebrandt GmbH

IN BRIEF

SAFETY AND SECURITY STANDARDS

WHAT REQUIRES PROTECTION?

APPLYING SAFETY PRINCIPLES TO SECURITY

INTEGRATING BPCS AND SIS

IT SECURITY AND SAFETY RECOMMENDATIONS

When the Stuxnet computer worm attacked programmable logic controllers (PLCs) at Iranian nuclear facilities running an integrated system, centrifuges were commanded to literally rip themselves apart. This clear demonstration of the link between cybersecurity and safe industrial operations was a worldwide wakeup call for plant managers, IT and automation managers, safety engineers and many others.

Of course, smaller-scale attacks are much more likely, and they are happening. At one plant, where system maintenance was carried out remotely, a cyber attack from abroad revealed the vulnerability of using simple username/password authentication for remote access. The attack was discovered only after the data transmission volume exceeded the company's data plan.

Cyber-related safety risks do not necessarily result from criminal activity. During the commissioning of one plant, for example, the failure of engineering software during the recompiling of the memory mapped input (MMI) following a plant shutdown led to a situation in which an incorrect modification was loaded into an integrated safety controller, and then activated.

These incidents demonstrate the need for specific IT security improvements, and at the same time, raise broader questions about

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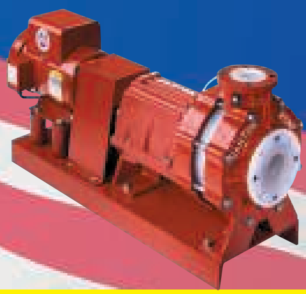

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FIGURE 1. Under a model put forth under IEC standard 61511, an industrial process is surrounded by a series of risk-reduction layers that act together to lower risk

the relationship between cybersecurity and plant safety:

1. Can the "insecurity" of integrated control systems influence the functional safety of a plant?
2. What needs to be protected?
3. Can the principles developed for functional safety be applied to security?

This article considers these questions and includes operational examples and specific recommendations for improving security and safety at industrial facilities.

Safety and security standards

The International Electrotechnical Commission (IEC; Geneva, Switzerland; www.iec.ch) standard IEC 61508 is the international standard of rules for functional safety of electrical, electronic and programmable electronic safety-related systems. According to IEC 61508, functional safety is "part of the overall safety that depends on functional and physical units operating correctly in response to their inputs."

By this definition, the answer to the first question posed earlier — Can the "insecurity" of integrated control systems influence the functional safety of a plant? — has to be "yes." In the examples cited above, vulnerabilities to people and facilities were introduced. Clearly, functional safety was compromised, and while security breaches may not have led to deaths or injuries, there is no evidence to suggest that such a situation could not occur in the future.

Even ruling out malicious threats, the fact remains that IT security-based vulnerabilities can be found in all kinds of automation systems. This includes the safety-related system itself and the distributed control system (DCS), of which the safety system may be a part. This is one reason why so many safety experts call not only for the physical separation of safety instrumented system (SIS) and DCS components, but also for different engineering staffs or vendors to be responsible for each.

To answer the other questions, we need to highlight two other standards. One is the international standard IEC 61511 for SIS in the process industries. Whether independent or integrated into an overall basic process control system (BPCS), the SIS is a fundamental component of every industrial process facility.

In this model, the industrial process is surrounded by different risk-reduction layers, which collectively lower the risk to an acceptable level (Figure 1). The risk reduction claim for the safety layer is set by the safety integrity level (SIL).

The first line of protection for any plant is the control and monitoring layer, which includes the BPCS. By successfully carrying out its dedicated function, the BPCS reduces the risk of an unwanted event occurring. Typically, IEC 61511 stipulates that the risk reduction claim of a BPCS must be larger than 1 and smaller than 10. A risk-reduction capability of 10 corresponds to SIL 1.

The cyberattack and IT vulnerability prevention layer includes the SIS. The hardware and software in this level perform individual safety instrumented functions (SIFs). During the risk and hazard analyses carried out as part of the basic design process of every plant, the risk-reduction factor to be achieved by the protection layer is determined.

In most critical industrial processes, the SIS must be rated SIL 3, indicating a risk-reduction factor of 1,000, to bring the overall risk to an acceptable level.

At the mitigation layer, technical systems are allocated, allowing mitigation of damages in case the inner layers of protection fail. In many cases, mitigation systems are not encountered as being part of the safety system, as they are only activated after an event (that should have been prevented) happens. However, in cases where the mitigation system is credited as part of defining additional measures, it may be covered by the safety evaluation as well.

Now consider the IEC standard for cybersecurity. IEC 62443 covers the safe security techniques necessary to stop cyber attacks involving networks and systems at industrial facilities.

What requires protection?

According to the most recent version of IEC 61511, the answer to the question of what needs to be protected is that both norms and physical structures need to be protected. As for norms, the standard calls for the following:

- SIS security risk assessment
- Making the SIS sufficiently resilient against identified security risks
- Securing the performance of the SIS system, as well as diagnostic and fault handling, protection from unwanted program alterations, data for troubleshooting the SIF, and bypass restrictions so that alarms and manual shutdown are not disabled
- Enabling/disabling of read/write access via a sufficiently secure method
- Segregation of the SIS and BPCS networks

As for the structural requirements, IEC 61511 instructs operators to conduct an assessment of their SIS related to the following:

- Independence between protection layers
- Diversity of protection layers
- Physical separation between different protection layers
- Identification of common-cause failures between protection layers

One other IEC 61511 note has particular bearing on the issue of cybersecurity and plant safety. The standard states: "Wherever practicable, the SIF should be physically separated from the non-SIF." Also, the standard demands that countermeasures be taken for foreseeable threats.

Applying safety principles

The IEC 61511 (safety) and IEC 62443 (security) standards coincide on the demand for independent layers of protection. Together, these standards prescribe:

- Independence between control systems and safety systems
- Reduction of systematic errors
- Separation of technical and management responsibility
- Reducing common-cause errors

The standards also reinforce that anything and everything within the system is only as strong as its weakest link. When using embedded safety systems, all hardware and software that could impair the safety function negatively should be treated as being part of the safety function.

IEC 61511 requires different, independent layers of protection. Unifying two layers of protection will require the new risk-reduction evaluation to prove that compliance with the overall risk reduction is reached when two different protection layers are in place.

Integrating BPCS and SIS

As an illustrative example, assume that a risk analysis of a given process has led to the conclusion that a SIL-3-compliant SIS is required. The traditional approach implies that a risk reduction of greater than 1,000 and less than 10,000 will be achieved. The risk reduction is partly covered by the BPCS (up to 10, as per IEC 61511) and by the SIS (1,000 in a SIL-3-compliant solution).

In the integrated solution, there will be common components for the BPCS and SIS. Depending on the individual setup, this will be either the central processing unit (CPU), input-output (I/O) buses or (parts) of the solution software (for example, the operating system), and symbol libraries.

The argument could be made that different components (of the same make) may be used for the SIS and BPCS. However, if common elements (such as operating systems and buses) are used, the systematic capabilities of such components may need to comply with the requirements mentioned above.

It should also be kept in mind that using components such as CPUs with freely configurable software on board – and using these same components for different tasks – may not be considered sufficient leveraging of the integrity level of the solution.

These commonly used components, in order to comply with the initial risk reduction requirements, will need to maintain a risk reduction of greater than 1,000 by less than 10,000. Practically, this means SIL 4, which is currently an unachievable level.

Engineering's key role in security

The quality of engineering processes, tools and associated services may be even more important to overall safety results than BCPS and SIS hardware.

Proper engineering includes the following aspects:

- Reducing complexity by splitting tasks into independent modules
- Properly defining and verifying interfaces
- Testing each module intensively
- Maintain the "four-eyes" principle when reviewing engineering documents and results of implementation tasks, according to IEC 60158-1, paragraph 8.2.18

Application of this strategy requires engaging the various parties to make sure that potential deficiencies in each task are identified and corrected. While integrated tools can support the effectiveness of engineering processes, addressing aspects like common-cause failures requires first narrowing integration to a sustainable level. This helps maintain both efficient engineering processes and functional safety at the required level.

The previous comments about BPCS and SIS independence and diversity also apply to engineering tools. A potential hidden failure of the engineering tool may impair the desired reduction in overall risk.

There are two types of integrated solutions that have either a common configuration database for SIS and BPCS, or have independent databases for SIS and BPCS, but use the same data access mechanisms. Both solutions have the disadvantage of having a common cause for potential failures, which would infect both the BPCS and SIS.

The quality of engineering processes, tools and associated services may be even more important to overall safety results than BCPS and SIS hardware.

The engineering tool for safety systems should overcome these issues by remaining independent (to the greatest extent reasonably possible) from the hardware and software environment. This is accomplished by having the complete functionality of the safety engineering tool, running in a Windows software environment, implemented in a way that allows it to be independent from Windows functions. This concept allows maximum protection from errors and creates a trusted set of engineering data that can be used to program the SIS.

Nevertheless, the engineering tool should allow integrated engineering by maintaining interfaces that permit automated transfer of configuration data (tag-oriented information as well as logic-oriented data) from third-party systems into the trusted set of engineering data used for programming the SIS.

Furthermore, having the same engineers in charge of programming the DCS and safety system ignores the proven benefits of the checks and balances of independent thinking. For this reason, IEC 61508 is setting recommendations for the degree of independence of parties involved in design, implementation and verification of the SIS.

IT security recommendations

Cybersecurity and plant safety are so intertwined in the connected world of industrial processes that an equal commitment to both is required to achieve the needed protection. Following the recommended international standards for functional safety for PLCs (IEC 61508), safety instrumented systems (IEC 61511) and cybersecurity (IEC 62443) provides a path to a safe, secure facility.

For the most robust security and reduced safety risks, the author advocates the traditional approach of standalone SIS and BPCS units — ideally from different vendors — versus an integrated BPCS/safety system from the same vendor.

For valid security and safety reasons, it is also good practice for companies to consider an independent safety system built on a proprietary operating system. Of course, such a system can and should be completely compatible with DCS products. Additionally, it should feature easy-to-use engineering tools with fully integrated configuration and programming and diagnostic capabilities.

Applying these recommendations and adhering to international standards for separate BPCS and SIS systems help plant operators meet their obligation to protect people, communities, the environment and their own financial security. The good news is that hardware, software and expertise are available today to help operators meet their obligations for the full lifecycle of their plants. ■

Edited by Scott Jenkins

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Onsite Nitrogen Generation Via PSA Technology

Ongoing advances in both adsorbent materials and system engineering allow today's pressure swing adsorption (PSA) systems to produce nitrogen of varying purities and volumes at relatively low cost compared to cryogenic air separation

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Nitrogen production that is carried out using pressure swing adsorption (PSA) technology over a carbon molecular sieve (CMS) is considered to be a mature, cost-effective and highly efficient method to produce nitrogen to meet a wide range of purity and flow requirements. Ongoing increases in efficiency in PSA-based nitrogen-generation facilities are being driven by enhanced CMS materials (Figure 1) and process improvements. This article provides an overview of the fundamentals of PSA-based nitrogen generation, while focusing specifically on innovative practices and improved CMS materials. Together, these advances contribute to continuous improvement in PSA system performance, giving chemical process industries (CPI) plant operators a proven way to produce a reliable and low-cost supply of high-purity dry nitrogen onsite.

Introduction

Thanks to its inertness and low reactivity, nitrogen — in both the gaseous and liquid state — is used in a wide range of applications in many industrial sectors. These include the production of foods and beverages, chemicals and pharmaceuticals; petroleum processing; the thermal treatment of metals; the manufacture of flat glass, semiconductors and electronics; and many more. Industrial facilities that require large volumes of nitrogen always look for efficient methods of onsite nitrogen production to meet all of the specifications related to purity, flow requirements, power consumption, footprint and portability [*1*].

FIGURE 1. Carbon molecular sieve (CMS) pellets, typically manufactured from coconut shells, provide the surface area and pore structure needed to separate oxygen and nitrogen from a compressed air inlet stream (Credit: Comelt S.p.A.)

Nitrogen gas is produced by separating air into its primary component molecules (nitrogen and oxygen), using one of two methods: 1. Traditional cryogenic fractionation of air that has been liquefied; or 2. Separation of gaseous air using pressure swing adsorption (PSA) or membrane-based separation systems. If large volumes of nitrogen with extremely high purity (99.998%) are required, cryogenic fractionation of air remains the most efficient and economical technology option [*2*]. This is the oldest method of nitrogen production, and it has the ability to produce both gaseous and liquid nitrogen (for daily use and as a backup supply). Cryogenic fractionation of air is typically carried out in large-scale commercial plants that then deliver the produced nitrogen to users.

However, at many CPI facilities, enriched nitrogen is produced onsite using smaller-scale PSA separation or membrane-based separation systems. PSA systems operate on the principle of physical adsorption of the oxygen in air by carbon molecular sieve materials (such as those shown in Figure 1), leaving an enriched nitrogen stream as the product; the process is illustrated in Figure 2. Today's PSA systems can economically produce nitrogen from compressed air at a variety of volumes. For instance, today's systems can handle an inlet air stream of less than 5,000 to more than 60,000 std. ft^3/h, reliably producing N_2 that meets purity requirements from 95 to 99.9995% [*1*].

However, the capital and operating costs of a PSA system are directly correlated with the purity of the nitrogen produced, and these costs climb rapidly once nitrogen with purity greater than 99.5% is required. In some cases, it can be cost-effective to produce higher-purity nitrogen by first producing 99.5%-purity nitrogen using a PSA system, and then using a palladium or copper unit to remove residual levels of oxygen in the nitrogen product. Such systems can bring down residual oxygen to 1–3 ppm.

Membrane-based separation systems, which typically produce nitrogen at relatively low capacity (up

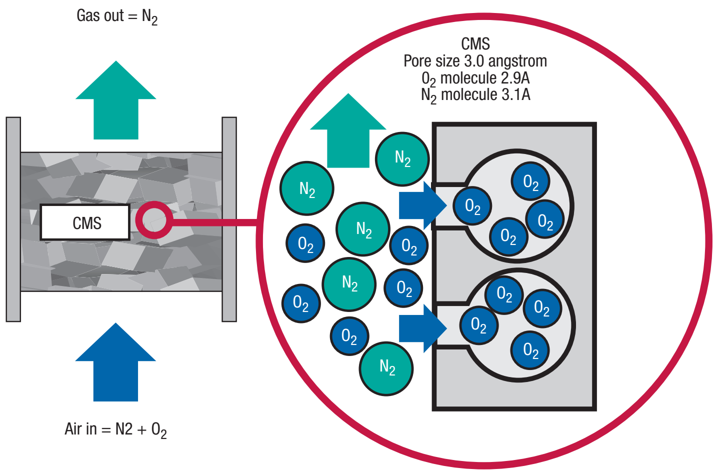

FIGURE 2. Within the CMS pellets, oxygen is preferentially adsorbed, allowing a nitrogen-rich product stream to be captured for use onsite (Credit: SHL)

to 40,000 std. ft^3/h) with a purity of 95–99.5%, use several semi-permeable membrane modules. Each membrane module contains thousands of hollow-fiber membrane strands that remove oxygen, water vapor and carbon dioxide from the compressed-air inlet stream, via selective permeation. Membrane technology is the newest of the three nitrogen-production options (introduced more recently than cryogenic and adsorption processes). In recent years, ongoing improvements in membrane materials have helped to make membrane systems attractive for somewhat larger nitrogen flow requirements.

Selecting the right system

When selecting the most appropriate nitrogen-production process, several parameters should be considered. Purity and capacity are the most important factors that can affect the choice of production methodology, and hence, have a direct impact on the unit cost of the nitrogen produced. The use of a PSA nitrogen-generation system, which can be designed to meet all types and patterns of nitrogen flow — steady, periodic and erratic — has grown in popularity during the last several decades, thanks to the simplicity, performance, flexibility, reliability and relatively low capital and operating costs of this production route.

However, the optimal nitrogen-production rate using a PSA system based on CMS pellets is around 3,000 Nm^3/h of N_2 produced (>95% purity). Within that range, PSA is a more economical option than O_2/N_2-separation by air liquefaction and cryogenic separation, or by membrane-based separation. The principles of PSA-based nitrogen-generation technology using CMS and several important aspects of process engineering knowhow are discussed below.

Carbon molecular sieves

CMS is part of a special class of activated carbons that have non-crystalline (amorphous) structure with a relatively narrow pore-size distribution. This material provides molecular separations based on the rate of adsorption of nitrogen, rather than the differences in adsorption capacity between oxygen and nitrogen. Figure 2 shows the inner structure of a CMS material that is appropriate for the separation (removal) of O_2 molecules from N_2 molecules in the compressed-air inlet, to yield an enriched nitrogen stream (Note: Carbon molecular sieves are selective for oxygen, while zeolite molecular sieves are selective for nitrogen).

CMS that is used to separate nitrogen and oxygen from air in PSA systems is typically manufactured from coconut shells, in pellet form, with pellet diameter from 1.0 to 1.8 mm. Such pellets have the most suitable pore size and maximum surface area to allow for the separation of nitrogen and oxygen from air during the continuous, cyclical process of adsorption (pressurizing) and desorption (depressurizing).

Due to the presence of micropores in a very small size range, oxygen molecules are able to penetrate the CMS pellets relatively fast, whereas the slightly larger nitrogen molecules take more time to penetrate the CMS material and be adsorbed (Figure 2). Initially, oxygen preferentially enters the micropores. However, after a few hours, equilibrium is achieved and when that occurs, CMS adsorbs roughly equal amounts of nitrogen and oxygen.

To meet longterm performance objectives, the CMS media must be replaced regularly. If system performance begins to decline, the CMS also should be replaced, and such a revamp provides a good opportunity to adjust or update the existing design concept to ensure that the desired nitrogen requirements are still being met

Nitrogen production via PSA

The PSA process makes use of cyclic pressurization and depressurization steps, where more oxygen is adsorbed on the CMS during the high-pressure cycle, and then released when the pressure is reduced. Figure 3 shows a typical PSA nitrogen-generation system, consisting of two interconnected CMS (adsorber) columns that have automatic changeover valves. Through cyclic operation of the valves, the two columns alternate in function, so that compressed, dry air flows into one column (during the adsorption phase). Once the adsorption phase is complete and the pressure in that column is reduced (toward atmospheric pressure), depressurization takes place (desorption phase). Assuming that Column C1 is operating in adsorption mode, the CMS in that tank adsorbs oxygen from the inlet air and the product nitrogen stream leaves the adsorber and is fed to the end user via a receiver tank.

At the same time, the second column (C2) is operating in its desorption phase. As C2 is depressurized toward atmospheric pressure, the oxygen that was adsorbed by the CMS media is released, creating an oxygen-enriched gas (off-gas) that is vented to the atmosphere as an inert exhaust stream.

Once the operation cycle is complete, the valves are activated in such a way that C1 again operates in desorption mode, while C2 operates in adsorption mode. This cyclic pressure-swing operation allows for continuous nitrogen production.

Short cycles between adsorption and desorption are typically adopted, in order to obtain the higest possible oxygen load by the CMS media (to allow the target nitrogen stream to be quickly and efficiently separated from the inlet compressed-air stream). In a typical PSA system, the usual adsorption-desorption cycle time lasts just 45 to 90 seconds. At the end of the desorption cycle, pressure is equalized between the two adsorbers (for a few seconds), and another cycle begins.

For the sake of process optimization, the pressure release into the atmosphere can be cut off shortly before the end of the cycle by closing the waste-gas valve. This so-called "cutting technique" leads to higher nitrogen purities (<1 vol.% residual oxygen in the product nitrogen stream), because toward the end of each desorption cycle, a major proportion of nitrogen still remains in the pore structure of the CMS substrate. This provides a slight initial pressure of pure nitrogen at the start of the next adsorption cycle, which benefits the overall adsorption sequence.

The cutting time (to achieve oxygen content in the product nitrogen of <1%) is typically set according to the following procedure:

- Measurement of O_2 concentrations in the exhaust gas
- Observation of the (declining) O_2 concentrations in the exhaust gas
- Determination of the time taken up to the moment when the dropping O_2 concentration has gone down to 21 vol.%.

The time measured (in seconds), plus the cutting time to which the closing times of exhaust valves, is typically set via a controller.

PSA plant configuration

A standard PSA nitrogen-generation plant typically includes four major sections:

1. Air compressor for the inlet air
2. Air pretreatment (which typically involves the use of a mist eliminator to remove water droplets and very small amounts of entrained oil, plus a carbon filter to remove residual oil vapors prior before the inlet stream enters the buffer tank)
3. Adsorption-desorption columns
4. Product-delivery system (typically

FIGURE 3. A typical onsite PSA system uses two vessels, both filled with CMS pellets. They operate in an alternating mode, so that at any time, one is in pressurization mode to enable air separation (to allow the nitrogen product stream to be collected), while the other tank is in depressurization mode, to allow the adsorbed oxygen to be released to the atmosphere (Credit: Claind S.r.l.)

a nitrogen receiver/buffer tank plus an oxygen analyzer ahead of delivery to the customer)

Similarly, PSA nitrogen-generation plants are usually operated with an upstream refrigeration dryer (Note: The use of refrigerated dryers eliminates the requirement for purge air, resulting in a capital-cost reduction, but this design introduces more water vapor into the CMS columns [*1*]). As an alternative, the PSA system can also be operated with a desiccant layer arranged in the bottom part of the PSA adsorbers to remove moisture from the inlet air stream.

To ensure reliable operation of the PSA plant, moisture in the inlet air should be maintained at rate lower than the rate corresponding to the pressure dewpoint +2°C (<5.57 g H_2O/m^3 of air at 8 bars). Excessive levels of moisture will contaminate the CMS columns and reduce the efficiency of the nitrogen generation process.

Long-term practical experience with PSA plants has shown that, as long as the specified conditions are strictly observed, the entire CMS bed can expect a lifespan of five years or more. The CMS material must be filled homogeneously into adsorbers, and these vessels should be equipped with a bottom gas-inlet system. The recommended procedure is to fill the CMS pellets homogeneously into adsorbers using the snow-storm-filling device, which distributes the desiccant and CMS evenly over the entire adsorber cross-section as it enters the column. This procedure ensures the highest bed densities in one filling step (higher than that produced using vibration or other commonly used methods), and leads to optimal system performance.

Regular maintenance is key

To meet longterm performance objectives, the CMS media must be replaced regularly, according to system-specific revamp requirements. If the performance of an existing PSA facility begins to decline, the CMS should be replaced. Such a revamp provides a good opportunity to adjust the existing design concept to ensure that the nitrogen requirements of the user are still being met. Upgrading to the most modern CMS materials allow operators to optimize the existing plant toward higher production rates and better gas quality. Along with a safety inspection and replacement of worn parts, such a periodic inspection, upgrade and retrofit allows operators to stay abreast of the most state-of the-art technology.

The inherent flexibility and reliability of today's PSA systems provides many advantages, allowing CPI operators to produce nitrogen in the required purities and volumes, to meet a diverse range of chemical process applications. Ongoing advances in both the CMS adsorbent materials and the overall process design and engineering have led to continuous improvements and advancements of such systems for air separation, allowing them to be used as a cost-effective alternative to more costly cryogenic air separation in many applications. ■

Edited by Suzanne Shelley

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Beyond Gravity: Centrifugal Separations in CPI Operations

Follow these recommendations to select the right centrifuge for your application

Alan Gabelman
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Many chemical process operations require the separation of multiple phases. This can be done in a number of ways, including simple gravity separation, traditional or crossflow membrane filtration and centrifugation. This article focuses on centrifugation, which is a phase-separation brought about by exertion of a centrifugal force greater than the force of gravity. While centrifugal separation of a solid from one liquid phase is most common, centrifuges are also employed to separate two liquid phases, and to separate two liquids and a solid phase. Unless otherwise mentioned, separation of a solid from one liquid phase is assumed in the discussion that follows.

Separating solids from liquids

The objective of a centrifugation process is either clarification, solids concentration or classification. Each is discussed below.

Clarification. The goal of clarification is to obtain a liquid phase (known as supernatant) that is clear. This may require discharging more liquid with the solids than would otherwise be necessary, to ensure that the resulting supernatant is in fact solids-free. The separated solids are discharged as a wet paste, sludge or concentrated slurry.

Solids concentration. With this objective, the exiting solids stream needs to contain as little liquid as possible. This often requires removal of fine solids with the supernatant, which can render the supernatant cloudy.

Classification. With classification — the least common of the three objectives — the goal is to separate the solids into fractions with different particle size ranges.

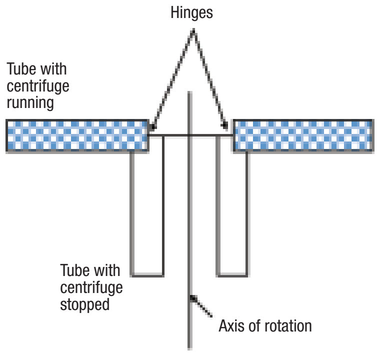

FIGURE 1. Feed slurry can be characterized using a simple laboratory centrifuge, such as the one shown here

Each of these objectives must be defined in sufficient detail to ensure that the centrifuged product will meet the specifications. If the objective is solids concentration, how concentrated do the solids need to be? Is there a moisture specification that must be met? If the goal is clarification, what level of clarity is sufficient? Some applications require a quantitative measure of clarity, which may be expressed as percent transmittance of visible or ultraviolet (UV) light at a specified wavelength. In other cases, a qualitative visual characterization may suffice.

If the supernatant needs to be sparkling clear — as required for some fruit juices and other beverages — centrifugation alone may not be the best approach. A more economical solution may be to deliver a turbid supernatant, then carry out further clarification using a downstream polishing filter.

For classification, relevant questions to ask include: How many fractions are needed, and what is the required particle size range of each? The particle-size distribution can be determined from the pattern and intensity of scattered light that is obtained when a laser beam is passed through the sample — a technique known as laser diffraction.

FIGURE 2. Shown here is a vertical basket centrifuge (Credit: Western States)

In addition to the process objective, selection of the best type of centrifuge for a particular application depends on a number of other factors, including the required capacity and the physical properties of the feed. Properties that directly impact the type, as well as the size, of the centrifuge needed include the density difference between the solids and the liquid phase, the particle size and shape, and the liquid viscosity.

The ease of separation increases with an increase in the density difference between the solids and the liquid, meaning less force is needed and a smaller centrifuge (or a centrifuge operated at a lower rotational speed) can be used to obtain a given throughput.

Smaller particles are more difficult to remove than larger ones, because in general, the sedimentation rate increases with the square of the particle diameter. The centrifuge design needs to be based on the smallest

TABLE 1. G-FORCES DEVELOPED BY VARIOUS TYPES OF CENTRIFUGES [FROM REF (1)]	
Single-chamber bowl centrifuge	600 –1,200
Decanter centrifuge	2,000–5,000
Multichamber bowl centrifuge	5,000–9,000
Disk stack centrifuge	5,000–15,000
Laboratory bottle centrifuge	2,000–20,000
Tubular centrifuge	12,000–62,000
Ultracentrifuge	20,000–1,000,000

particle to be removed. However, not only is the particle size important, but also its shape. For example, flat, elongated particles tend to settle more slowly than spherical ones. In addition, solids tend to settle more slowly with increasing liquid viscosity, requiring a larger centrifuge or higher rotational speed to achieve the desired capacity.

The undissolved solids content of the feed must also be considered. Values can be expressed using either a weight or volume basis. Percent by volume is usually used, but not always, so the basis must be made clear. In addition to solids content, the nature of the settled solids must be understood to allow the best type of centrifuge to be selected. For example, solids may pack into a hard, firm cake, or the packed solids may be soft and loose.

Additional considerations

Solids discharge may be manual or automatic, with the latter either intermittent or continuous, and the desired method must be specified. In addition, do the solids need to be washed, and if so, how much? If the solids are the product, then displacement of residual liquid using a wash solvent (usually water) may be needed to remove contaminants. On the other hand, if the liquid is the valuable phase, washing may be needed to maximize liquid recovery from the solid.

Other considerations include the following: Is the feed flammable, toxic or corrosive? Are there any unusual operating conditions, such as elevated temperature or pressure? Is aseptic operation needed, as in some biotechnology applications? Are the feed solids abrasive or fibrous? Is there a tendency for solids to crystallize? Does significant foaming occur? Suitable centrifuge designs are available to handle all of these situations.

Small-scale testing

Much can be learned by using a simple laboratory centrifuge, such as the one shown in Figure 1. This device consists of an even number (typically four to eight) of tubes that rotate around the central axis. In most designs, glass or plastic tubes are placed inside of stainless steel holders that are hinged to the rotor. When at rest, the tubes are vertical; upon rotation, centrifugal force orients them horizontally.

The tubes are filled with the starting material, and the rotational speed is set so that the applied force is 1,000 times that of gravity, or 1,000G (see the explanation below). The time required to obtain clear liquid or fully settled solids is then determined; the typical time is between 30 s and 20 min.

Often the tubes are graduated, so that the volume percent solids can be read directly. One can assess the nature of the settled solids (for instance, firm and hard-packed, or soft and loose) simply by poking them with a glass rod. Information obtained from this simple test can provide important insight into the size and type of centrifuge that may be suitable for the application.

G-force and sigma factor

The centrifugal force developed by a centrifuge is expressed as a multiple of the force of gravity. This force, known as the G-force, is proportional to the distance from the axis of rotation and the square of the rotational speed:

$$G = \frac{39.48n^2}{g} \quad (1)$$

Where:
G is the G-force
n is the rotational speed, revolutions per second (rev/s)
r is the distance from the axis of rotation, cm
g is the acceleration due to gravity, which has a conventional standard

TABLE 2. SIGMA FACTORS FOR VARIOUS COMMERCIAL CENTRIFUGES [1]	
Batch solid bowl centrifuge	20 – 200 m^2
Decanter centrifuge	150 – 2,500 m^2
Tubular centrifuge	2,000 – 3,000 m^2
Disk stack centrifuge	400 – 120,000 m^2

value of 981 cm/s^2, but depends on the altitude

Equation (1) clearly indicates the primary parameters available to the designer to obtain the desired G-force — that is, the diameter and rotational speed of the rotor.

Note that the G-force is not uniform throughout the centrifuge. The force is smallest near the axis of rotation, and then increases linearly in the radial direction. Typical G-forces developed by several types of centrifuges are shown in Table 1. Values vary widely, ranging from a low of 600 for the single-chamber bowl centrifuge, to as high as 1,000,000 for the ultracentrifuge. Values at the high end are sufficient to remove macromolecules, such as nucleic acids.

While the G-force is an important characteristic of a centrifuge, it may not be an accurate indicator of separation capability. This is because centrifuge performance is impacted not only by the applied force, but also by the area available for settled solids. That is, for a given applied G-force, a centrifuge with more settling area offers greater separation power.

A better measure of the separation capability of a centrifuge is its sigma factor, Σ, which is defined as the cross-sectional area of a gravity settling tank that would give the same separation performance. Values depend on centrifuge geometry and configuration (for instance, the size and number of settling surfaces), in addition to the G-force. For some types of centrifuges, equations for direct calculation of the sigma factor are given in engineering handbooks.

Typical sigma factors for several types of centrifuges are provided in Table 2. As with G-force, Σ values vary widely, ranging from a low of 20 m^2 for the batch solid bowl, up to 120,000 m^2 for the disk-stack centrifuge. Although the decanter is highly versatile and widely used, as discussed below, its sigma factor is relatively low because of its relatively low settling area. Conversely, the disk stack centrifuge contains a large number of disks, providing substantial settling area, and in turn, a high sigma factor. Please note that the sigma factors shown in Table 2 are only approximations; because of complex flow patterns within the centrifuge, actual performance may deviate by as much as 50% from the given values.

Sigma factors can be employed to size a production-scale centrifuge using pilot data obtained with the same type of centrifuge, according to the relationship shown in Equation (2):

$$Q_2 = \frac{Q_1 \Sigma_2}{\Sigma_1} \quad (2)$$

Where:

Q is the flowrate

Σ is the sigma factor

Subscripts 1 and 2 refer to pilot and production scale, respectively.

Equation (2) says that if an optimized throughput of Q_1 is obtained with a pilot centrifuge having a sigma factor of Σ_1, then a production unit with a sigma factor of Σ_2 will be needed to obtain the desired production flowrate of Q_2.

Equation 2 can also be used to determine if the desired throughput can be achieved with an existing centrifuge with a known value of Σ_2. That value and the pilot data are used to calculate Q_2, which is then compared to the desired value to see if the centrifuge is suitable. However, because of the approximate nature of sigma factors, results obtained using this approach should be regarded as no more than rough estimates.

There are two broad classes of centrifuges, characterized by the nature of their solids collection surface. In filtering centrifuges, solids collect on a perforated surface, while supernatant flows through the perforations to a collection vessel. These centrifuges are actually filters, but unlike conventional filters (which operate using applied pressure or vacuum), the motive force in a filtering centrifuge is centrifugal force. Alternatively, sedimenting centrifuges use a solids collection surface that is not perforated. Examples of each type of centrifuge are described in the paragraphs that follow.

Filtering centrifuges

Basket centrifuge. This type of centrifuge, shown in Figure 2, contains a cylindrical, perforated basket (usually covered with a cloth liner) that rotates inside of a stationary housing. Basket diameters range from 75 to 120 cm, with diamete-to-height ratios of 1–3. Usually the axis of rotation is vertical, but horizontal machines are also used.

After accelerating the basket (also called the bowl) to the desired operating speed (typically 600–1,800 rpm), feed slurry emanating from one or more feed nozzles is directed toward the surface of the liner. Solids collect on the liner to form a cake, while clarified liquid passes through and exits at the supernatant outlet port.

After the cake reaches the desired thickness (typically 5–15 cm), feed is shut off, while the basket continues to rotate to allow further removal of liquid. The cake is then washed, usually with water, to displace the process liquid retained by the cake [2]. Afterward, the basket is acceler-

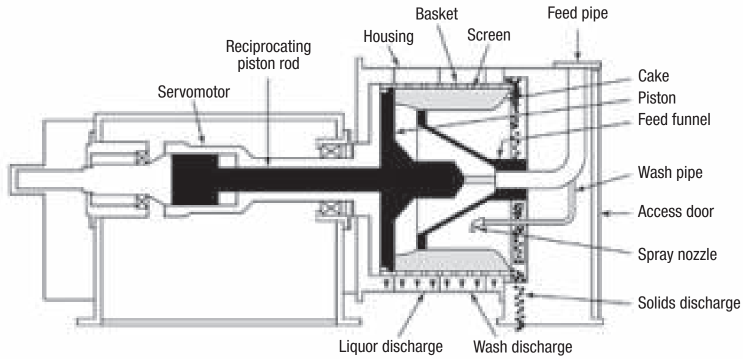

FIGURE 3. A pusher centrifuge is shown here (Adapted with permission from Ref. 4)

ated to near maximum speed to remove as much liquid as possible.

Finally, after decelerating to a suitably low rotational speed, cake is scraped away by a knife (also called a plow), which advances toward the liner by hydraulic action. The unit shown in Figure 2 also contains a plastic blade to sweep away the scraped solids. After plowing the cake, which falls to a tank, hopper or conveyor below, the bowl again accelerates and the cycle is repeated. The length of time for each step, as well as the flowrates of feed slurry and wash water, are optimized for the particular application. Cycle time is usually 2–6 minutes, but can be as long as 30 minutes, for example, if multiple washings are needed.

In general, basket centrifuges work best for relatively large (>5 µm) particles that form free-draining cakes, with feed slurry concentrations of at least 5 vol.%. One such application is recovery of sugar from crystallizer slurry. Centrifuges used for sugar recovery are rather large, with heights and diameters up to 115 and 185 cm, respectively, and deliver over 1,500 L of cake every three minutes.

For viscous feeds, such as sugar slurries, feed is introduced through a bottom valve and climbs the basket wall, rather than entering through a nozzle that is angled toward the basket. Because the high solubility of sugar would lead to excessive losses if washing were done with water, the cake is cleaned using superheated steam instead. In general, such a cake is too large to be covered entirely by the knife, so a moveable knife plows the cake in sections.

Conical basket centrifuges. As the name implies, this type of centrifuge has a basket that is conical in shape rather than cylindrical. The conical shape results in a component of centrifugal force that pushes the cake along the basket, leading to a continuous discharge of solids. To minimize friction, these units use only metal, rather than cloth, liners. Consequently, the solids particles must be at least 50 µm in size, because metal liners with holes smaller than that are difficult to manufacture. Continuous operation leads to much higher capacity for the conical basket centrifuge, compared to a cylindrical unit of similar size.

Pusher centrifuge. Similar in construction to the basket centrifuge, the pusher centrifuge contains a slotted bowl that is covered with a screen and rotates within a horizontal housing. Typical dimensions are 30–90 cm in dia. by 130–430 cm in length. As shown in Figure 3, this centrifuge also contains a pusher, which is a reciprocating disk that pushes the cake along the length of the bowl (which can also be called the basket or drum).

The pusher is driven by its own shaft, situated inside of the main shaft that drives the rotation of the bowl. After the reverse pusher stroke, feed slurry is directed to the slot on the bowl that was just pushed. Clarified liquid passes through, while solids collect on the surface to form

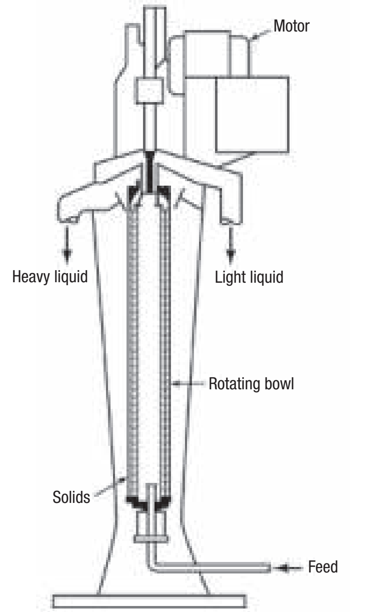

FIGURE 4. A tubular centrifuge is shown here (Adapted with permission from Ref. 4)

new cake.

The subsequent forward stroke pushes the cake the length of the stroke, typically <5 cm. In this manner, the cake moves along the length of the basket, drying as it goes. Usually the cake is washed somewhere in the middle of its travel. Eventually the cake reaches the end of the basket, then falls to a vessel or conveyor below. The reciprocation rate is typically <100 cycles/min.

In addition to the single-stage unit shown in Figure 3, there are also multistage pusher centrifuges. These contain multiple (typically 2–4) bowls of increasing diameter placed in series along the length of the housing. The first and each alternate bowl both rotate and reciprocate, while the other bowls only rotate. The pusher

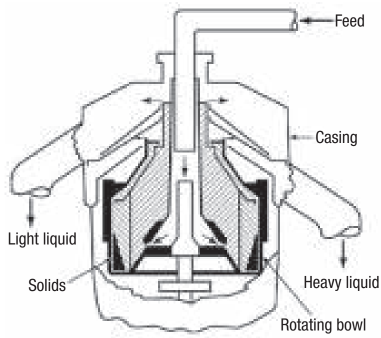

FIGURE 6. Shown here is a solid bowl disk centrifuge (Adapted with permission from [4])

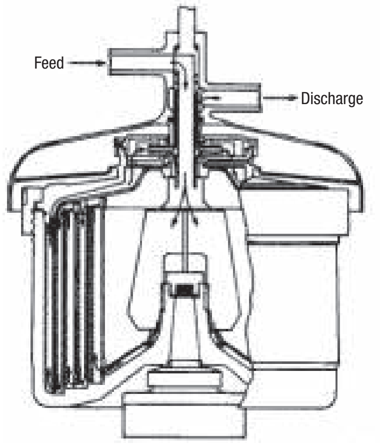

FIGURE 5. This multichamber bowl centrifuge has six chambers (Adapted with permission from Ref. 1)

pushes the cake from the first bowl, then each successive bowl (except the last one) pushes the cake that forms on the bowl ahead of it. The increasing bowl diameter with successive stages provides increasing G-force toward the discharge end, as the cake becomes increasingly dry and more difficult to dewater. Other advantages over single-stage units include less tendency of the cake to buckle because each stage is relatively short, and the ability to implement countercurrent washing for improved efficiency.

The pusher centrifuge is often an excellent choice for concentrated (>35 vol.% solids) slurries of large (>150 μm), free-draining particles, provided they form a cake with mechanical strength sufficient to withstand the pushing action. Thoroughly washed cakes with low moisture content are obtained with feed rates as high as 100 ton/h [*3*].

Sedimenting centrifuges

Tubular centrifuge. This type of centrifuge, shown in Figure 4, comprises a long, narrow tube that rotates at high speed within a cylindrical housing. A typical unit uses a tube that is 12 cm in diameter by 76 cm in length, and rotates at speeds as high as 15,000 rpm. Tubular centrifuges can handle solid-liquid, liquid-liquid, and liquid-liquid-solid applications.

The unit shown in Figure 4 is for the most general case: two liquid phases and a solid phase. Feed enters the rotating tube through a stationary nozzle at the bottom of the unit. Solids are driven to the wall, while the heavy and light liquids form concentric layers, with the heavy liquid adjacent to the solids and the light liquid closer to the axis of rotation.

Each liquid spills over a weir at the top of the centrifuge and then exits. At least one of the weirs is adjustable, and there is an optimal position that results in the best separation. This is because the position of the weirs determines the location of the liquid-liquid interface — and in turn the thickness of each liquid layer. The preferred weir position depends on whether removal of light liquid from the heavy layer, or heavy liquid from the light layer, is more difficult. For the former, the weirs would be positioned to increase the thickness of the heavy layer, as this provides additional residence time for the more problematic separation. Conversely, if removal of heavy liquid from the light layer is more difficult, greater thickness of the light liquid layer is preferred.

Advantages of the tubular centrifuge include high clarification ability, good solids drying, high G-force, and simple design and operation. Disadvantages are the inability to wash the solids, and the lack of a mechanism for automatic solids discharge. Regarding the latter, a tubular centrifuge must be manually disassembled and cleaned when the solids holding space is full, meaning solids removal is a batch operation. Only feeds with low solids content are suitable, to prevent the solids-holding space from filling too quickly. Tubular units work well for separation of fine particles (0.1–200 μm) from feeds containing no more than 0.5 vol.% solids, and for liquid-liquid applications.

Multichamber bowl centrifuge. This centrifuge contains a series of concentric bowls, with baffles to direct the flow. As shown in Figure 5, feed enters the center of the unit at the top, then flows outward. Because the G-force increases with distance from the center, successively finer solids are deposited onto the bowl walls as material moves toward the periphery. Consequently, this type of centrifuge provides classification of solids into different size ranges — one of the few designs that does so.

Supernatant flows inward from the outermost chamber, exiting through a central annular port.

These units have an aspect ratio of about one, smaller than the values of 5–7 that characterize tubular units. The additional collection surface provided by the multiple bowls allows feeds with higher solids content than tubular units, up to 5 vol.%. However, as with the tubular centrifuge, solids cannot be washed, and their removal requires manual disassembly and cleaning.

Disk centrifuge. In these centrifuges, the feed enters through the top near the axis of rotation, and is distributed among a stack of conical disks that divides the bowl. Solids are driven to the periphery of the bowl, while liquid moves toward the center and exits. A typical disk stack contains 30–200 disks, providing a considerable amount of settling area. The large number of disks reduces the settling distance (0.5–2 mm), and the incline (35–50 deg) facilitates outward movement of solids.

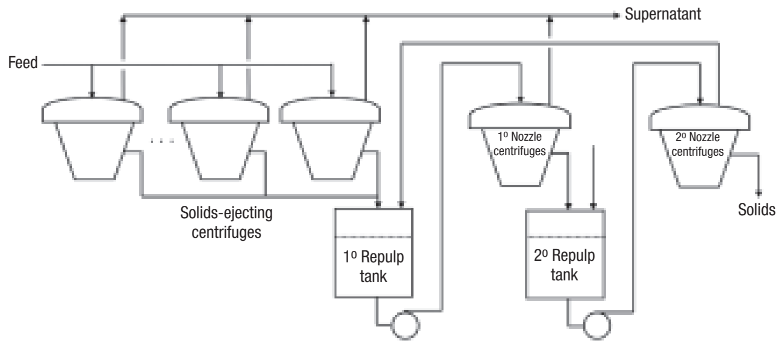

FIGURE 7. The disk centrifuge process shown here has two-stage countercurrent wash

Bowl diameters range from 20 to 80 cm, handling throughputs on the order of 4,000 L/min. There are several types of disk centrifuges, differing mainly in the method used to discharge the solids.

A diagram of a solid bowl disk centrifuge is shown in Figure 6. Again the diagram shows the most general case of two liquid phases and a solid phase. As with the tubular centrifuge shown in Figure 4, each liquid phase spills over a weir then exits, and the weir positions are selected for optimum performance. Solids (which cannot be washed) collect on the wall of the bowl, and are periodically removed by manual disassembly and cleaning. This limits the feed solids to a maximum of 1 vol.%, which is the main disadvantage of this type of centrifuge. The solid bowl design is better suited for liquid-liquid applications, and in fact, solid bowl disk centrifuges have been used for decades to separate cream from milk.

Solids-ejecting disk centrifuge. Unlike the solid bowl type, solids re-

TABLE 3. CHARACTERISTICS OF VARIOUS TYPES OF CENTRIFUGES (ADAPTED FROM REF. 1)									
Type	Solids discharge	Washing possibility	Duty[a]	G-force	Feed solids, % v/v	Particle size, µm	Feed rate, L/min	Settled solids consistency	Spin test time, min[b]
Basket, cylindrical	Intermittent	Washable	cr, sc, ls	600–1,800	>5	>5	Up to 800[c]	Granular solid	0–2
Conical basket	Continuous	Washable	cr, sc, ls	600–1,800	>5	>50	25–1,500	Granular solid	0–2
Pusher	Intermittent	Washable	cr, sc, ls	200–2,500	>35	>150	Up to 1,700	Granular solid	0–2
Tubular	Batch	None	cr, ls, ll, lls	12,000–62,000	<0.5	0.1–200	8–120	Firm cake	2–20
Multichamber bowl	Batch	None	cr, cl, ls	5,000–9,000	1-5%	0.5–5,000	1.5–350	Firm cake	2–20
Disk, solid bowl	Batch	None	cr, ls, ll, lls	5,000–8,000	<1.0	0.25–200	0.5–1,500	Firm cake	1–10
Disk, solids ejecting	Intermittent	None	cr, ls, lls	5,000–7,000	<10	0.5–200	4–1,500	Thick paste, flow-able	1–10
Disk, nozzle	Continuous	Some	cr, ls, lls	5,000–8,500	2-20	0.5–200	40–4,000	Concentrated slurry or sludge, flowable	1–10
Disk, nozzle-valve	Intermittent	None	cr, ls	14,000–15,000	<10	0.5–200	4–600	Thick paste, flow-able	1–10
Decanter, solid bowl	Continuous	Some	cr, sc, ls, ll	2,000–5,000	2–60	2–5,000	4–1,800	Flowable paste to granular solid	0–3
Decanter, screen bowl	Continuous	Washable	cr, sc, ls, lls	2,000–5,000	5–60	20–5,000	4–1,800	Granular solid	0–2

Notes:
a. cr: clarification; cl: classification; sc: solids concentration; ls: liquid-solid; ll: liquid-liquid; lls: liquid-liquid-solid
b.At 1,000G
c.Average over cycle

moval from the solids-ejecting disk centrifuge is automatic. The bowl of this type of centrifuge — also called an opening-bowl disk centrifuge — is divided horizontally into two parts, sealed with a gasket. The bottom piece acts as a sliding piston that periodically drops, opening the bowl to expose slots through which solids are ejected. Water (called operating water) pressure is used to open and close the bowl, which remains open for only 0.13–0.3 s per cycle. The time between openings is usually one to several minutes, but may be as long as several hours.

The opening frequency can be controlled by a timer, set based on experience, or by a turbidity sensor placed in the supernatant pipe. For the latter method, when the solids holding space is full, fine solids begin to find their way into the supernatant, increasing its turbidity. When a preset value is reached, the operating water valve automatically opens, causing the bowl to open and solids to eject. Ear protection is required, because the opening and closing of the bowl is quite loud.

Solids-ejecting machines handle slurry solids as high as 10 vol.%, although solids that tend to compact may cause difficulty. The solids, which cannot be washed, leave the centrifuge as a paste, less dry than the solids obtained with the solid-bowl units.

And, unlike the solid bowl version, solids-ejecting centrifuges are designed with clean-in-place (CIP) capability, meaning they can be cleaned without disassembly. This feature makes this type of centrifuge popular in food and pharmaceutical applications, including clarification of beverages (for instance, fruit and vegetable juices, beer, wine) and biomass removal from fermentation broths.

Nozzle-disk centrifuge. With this type of disk centrifuge, solids (in the form of a concentrated slurry or sludge) flow continuously through nozzles that are situated around the periphery of the bowl. Small nozzle centrifuges contain as few as two nozzles, while larger units have as many as 24, with openings of 0.5 to >3 mm. To minimize erosion, the nozzles are made from hard materials, such as tungsten carbide or various ceramics. Prefiltration of centrifuge feed may be necessary to avoid nozzle pluggage.

Like solids-ejecting centrifuges, nozzle units can be cleaned in place, again rendering them useful in food and pharmaceutical plants. Nozzle centrifuges are able to handle higher solids levels (up to 20 vol.%) than the solids-ejecting units. Moreover, the nozzle units can process the sticky, compacting solids that solids-ejecting machines find troublesome, and some designs allow introduction of wash liquids. On the other hand, the solids stream is more dilute than that obtained with the solids-ejecting centrifuge as it must be to flow through the nozzles. In addition, the nozzle unit requires about twice the power input of the solids-ejecting version.

Nozzle-valve disk centrifuge. These centrifuges should not be confused with the nozzle-disk centrifuge discussed above). These units are similar to the solids-ejecting unit, except that solids exit through elastomeric valves rather than slots. Each valve consists of an elastomeric disk attached to the slide ring that seals the bowl. A typical machine contains 12 valves. Operating water pressure forces the slide ring downward, opening the valves and discharging the solids. With opening times of only 0.07–0.10 s, these centrifuges are faster than the solids-ejecting units. The advantage is that less liquid is lost with the discharged solids. G-forces are as high as 15,000 — double those achievable by the solids-ejecting centrifuge, allowing the nozzle-valve version to compete with filters for applications that require high clarity or fine-particle separations. The main limitation is the inability to handle solids that compact, a result of the high G-forces at the periphery of the bowl. Like the solids-ejecting and nozzle-disk centrifuges, the nozzle-valve units can be cleaned in place. Feed solids are limited to 10 vol.%.

A disk centrifuge process with two-stage countercurrent washing of solids is shown in Figure 7. Solids from a bank of solids-ejecting cen-

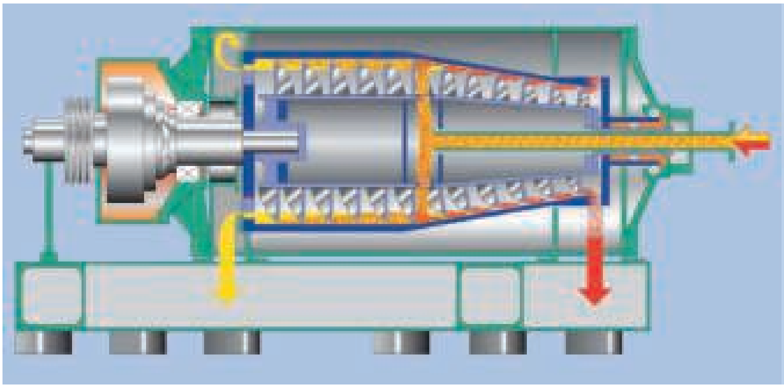

FIGURE 8. A solid bowl decanter centrifuge is presented (Source: TEMA Systems, Inc.; used with permission)

trifuges (perhaps 4–8) are washed using two nozzle units in series. Solids streams emanating from the solids-ejecting machines are collected in the primary repulp tank, where they are repulped (that is, washed) with supernatant from the secondary nozzle unit. The blended stream is fed to the primary nozzle centrifuge; supernatant is combined with the supernatants from the solids-ejecting units, and the solids are directed to the secondary repulp tank. There the solids are repulped with fresh water, and the combined stream is delivered to the secondary nozzle centrifuge. Supernatant is returned to the primary repulp tank, as mentioned above, and the twice-washed solids exit. This process leverages the advantages of two types of disk centrifuges to provide a high yield of supernatant, along with thoroughly washed solids.

Decanter centrifuge. A solid bowl decanter (Figure 8) comprises a bowl containing a cylindrical section (with a diameter of 15–140 cm) and a conical section, along with a scroll situated inside of the bowl. The bowl and scroll are each driven by their own shaft. Slurry is fed through a feed pipe to the center of the centrifuge, then moves toward the wall.

The solids collect at the wall, while the lighter liquid moves toward the axis of rotation. Because the scroll rotates at a slightly higher speed than the bowl, solids move to the conical part of the bowl, where they emerge from the liquid (called the pool) and are discharged. Solids that have emerged from the liquid make up what is known as the beach. Meanwhile, liquid moves to the opposite end of the bowl, where it flows over adjustable weirs prior to exiting.

The pool depth is controlled by the height of the weirs, and the optimum height depends on the process objective. A greater weir height results in a deeper pool, leading to longer residence time for settling of solids, and in turn better supernatant clarity. However, the beach is shorter with a deeper pool, and the solids are not as dry. Conversely, a lower weir height creates a more shallow pool, a longer beach, and drier solids — the tradeoff being less clear supernatant.

Screen-bowl decanter centrifuge. If both clear supernatant and dry solids are needed, then a screen bowl decanter centrifuge may be used. Here a cylindrical, screened basket is placed adjacent to the conical portion of the bowl, providing an opportunity for additional drying of solids, and if needed, washing.

Highly versatile, decanters can handle feeds containing up to 60 vol.% solids, at throughputs from four to 1,800 L/min. Solid bowl units can process solids as small as 2 µm, but to avoid loss of solids through the screen, the minimum size for the screen bowl decanter is 20 µm; both screen bowl and solid bowl decanter centrifuges handle particles as large as 5 mm. Consistency of discharged solids ranges from a flowable paste to a granular solid, with outputs of a few hundred kilograms to over 100 ton/h.

Clearly there are numerous types of centrifuges from which to choose. As a guide for selection, the key characteristics of the centrifuge design options discussed in this article are summarized in Table 3. The information there is general, and certainly there are exceptions. However, the guidelines shown can be used to narrow the choices, so that in-depth evaluation can focus on the types of centrifuges that are more likely to be feasible.

Centrifuge selection example

In this example, (adapted from Ref. 5), a centrifuge is needed for a solid-liquid separation, with a feedrate of 1,000 L/min. The objective is liquid clarification, and solids may exit as a concentrated slurry or sludge. Solids discharge must be intermittent or continuous, but not batch. In a laboratory spin test, the settled solids content was 15 vol.% , and liquid clarity was satisfactory after four minutes. Particle-size analysis gave a range of 2 to 10 µm. What type of centrifuge is suitable?

From Table 3, the only type that clearly meets all requirements is the nozzle-disk centrifuge. The solid-bowl decanter may also work, although the particle size result is at the very bottom of the acceptable range. Still, given the approximate nature of these guidelines, this centrifuge may warrant further investigation. The other types of centrifuges listed in Table 3 can be ruled out, because at least one aspect of each is clearly not suitable for the application. ■

Edited by Suzanne Shelley

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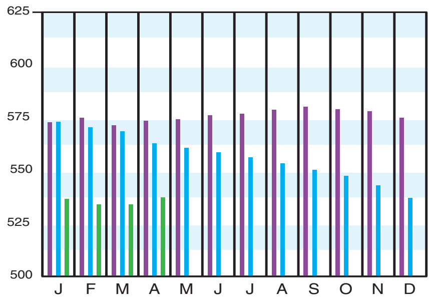
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Apr. '16 Prelim.	Mar. '16 Final	Apr.'15 Final
CE Index	537.3	535.3	562.9
Equipment	640.4	638.0	678.8
Heat exchangers & tanks	548.8	545.2	609.7
Process machinery	648.4	644.8	663.8
Pipe, valves & fittings	801.6	800.3	845.6
Process instruments	382.8	383.0	402.0
Pumps & compressors	970.5	969.7	958.4
Electrical equipment	508.2	508.3	511.9
Structural supports & misc	701.5	697.4	741.7
Construction labor	324.4	323.3	323.8
Buildings	540.8	538.4	545.0
Engineering & supervision	316.7	315.7	319.0

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

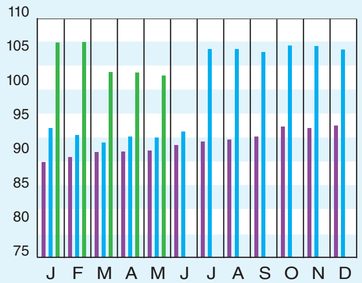


Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics

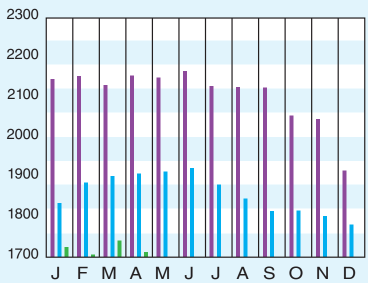
CURRENT BUSINESS INDICATORS

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2012 = 100)	May '16	=	101.6	Apr.'16	=	101.7	Mar.'16	=	102.2	May '15	=	101.2
CPI value of output, $ billions	Apr. '16	=	1,713.2	Mar.'16	=	1,702.4	Feb.'16	=	1,667.8	Apr. '15	=	1,869.1
CPI operating rate, %	May '16	=	74.7	Apr.'16	=	74.7	Mar.'16	=	75.1	May '15	=	74.9
Producer prices, industrial chemicals (1982 = 100)	May '16	=	225.0	Apr.'16	=	221.6	Mar.'16	=	219.2	May '15	=	248.5
Industrial Production in Manufacturing (2012=100)*	May '16	=	102.8	Apr.'16	=	103.2	Mar.'16	=	103.0	May '15	=	103.0
Hourly earnings index, chemical & allied products (1992 = 100)	May '16	=	164.4	Apr.'16	=	161.2	Mar.'16	=	160.1	May '15	=	159.1
Productivity index, chemicals & allied products (1992 = 100)	May '16	=	101.5	Apr.'16	=	101.9	Mar.'16	=	102.5	May '15	=	102.0

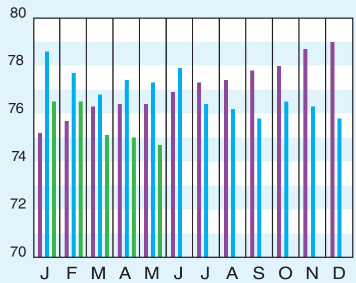
CPI OUTPUT INDEX (2000 = 100)†



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 April 2016 preliminary value for the *CE* Plant Cost Index (CEPCI; top; the most recent available) rose from the previous month, with all four major subindices experiencing increases. The March final values were upwardly revised from the values reported last month. The preliminary April 2016 CEPCI value is 4.5% lower than the corresponding value from April last year. This is again a smaller year-over-year difference than in the preceding several months. Meanwhile, the latest Current Business Indicators (CBI; middle) for May 2016 showed a small decrease in the CPI output index compared to the previous month. The April CPI value of output index was higher than the previous month, and producer prices edged higher again in May.

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Preliminary Agenda

*A **Keynote** address by Herman Purutyan, CEO of Jenike and Johanson will kick off the workshop and the following sessions will follow:*

Bulk Solids Characterization

The design of successful bulk handling installations starts with an understanding of the properties of the materials involved. This lecture covers the proper sampling of bulk materials and the measurement of the three key parameters for flowability analysis – cohesive strength, bulk density, and wall friction. Flowability measurements for product quality control are also reviewed, as are the two most common particle size measurement techniques – laser diffraction and sieve analysis.

Presenter: Timothy A. Bell, P.E., Engineering Fellow and Group Technology Leader, DuPont Engineering Research and Technology

Flow of Solids

The field of bulk material handling is quite complex. Bulk solids theory has unique terminology, scientific flow principles that are not the same as fluid or gas flow behaviors, and often are not taught to engineers at the university level. Personnel responsible for designing, fabricating, installing, and operating bulk material handling equipment are often unaware of the complex flow behaviors that can occur with bulk solids. Dr. Orlando will be covering the basics of Bulk Solids Handling while discussing Common Flow Problems, Material Testing, Design Considerations and Design Tools to solve your solids flow issues.

Presenter: Andrés Orlando, Ph.D., Project Engineer, Jenike & Johanson

Combustible Dust Safety

Many powders will burn slowly or with difficulty as a layer on a surface, but can explode if dispersed as a cloud. In fact, the vast majority of powders can form explosible dust clouds if the particle size is small, moisture content is low, and the dust cloud concentration (measured in g/m3) is above the Minimum Explosible Concentration (MEC). This presentation will discuss a well-tried approach to identify, assess, and eliminate/control dust explosion hazards in facilities. This presentation will also include the "Dust Hazard Analysis (DHA)" requirements of the New National Fire Protection Association (NFPA) 652: Standard on Fundamentals of Combustible Dusts.

Presenter: Vahid Ebadat, Ph.D., Chief Technology Officer, Chilworth Technology

Feeders and Rotary Valves

Virtually all solids handling systems require the metering of solids from one part of the process to the next, often with precise rate control, and sometimes across gas pressure differentials. This lecture covers most common feeding devices, with a particular emphasis on screw feeders used in loss-in-weight applications. Applications of rotary valves as feeders and as air locks will also be discussed, as will the role of rotary valve leakage in pneumatic conveying operations.

Presenter: Timothy A. Bell

Pneumatic Conveying

Although many pneumatic conveying equipment advances have been made, costly problems – including wear, attrition, rate limitation and line plugging – continue to occur. Brian will cover the basic components of pneumatic conveying systems, as well as discussing the basic troubleshooting of systems to identify issues in your lines.

Presenter: Brian Pittenger, Senior Consultant, Jenike & Johanson

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