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CHEMICAL ENGINEERING

December 2014

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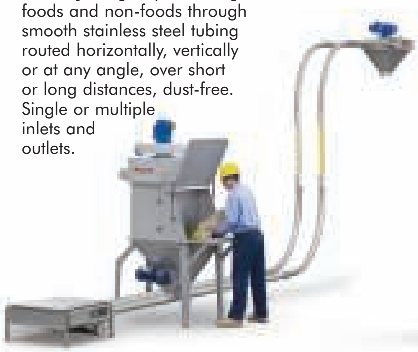

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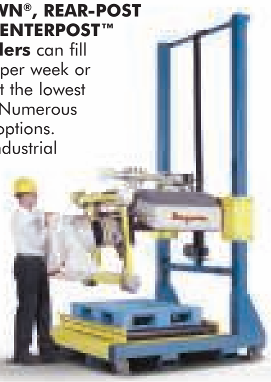

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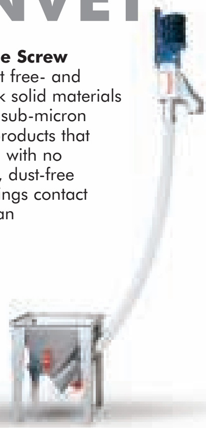

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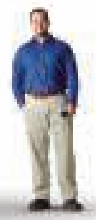

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Editor's Page

Redesigning our look

Technology continues to change at a rapid pace — particularly when we look at recent advances to our personal computers and mobile devices. As such, we at *Chemical Engineering* have been working on improving our online presence by taking advantage of some of the latest technological advances to help improve our readers' experience. Our goal is to make it easier to find and use our comprehensive articles, news and more information to help you do your job more effectively.

Some of the enhancements to our website include the following:

- More easily recognized components from our magazine to allow you to quickly find your favorite departments, such as Facts at Your Fingertips, Chementator and more
- An easier format for you to comment and provide feedback
- Better accessibility via mobile devices
- Improved navigation throughout the website
- Improved graphics
- A more seamless incorporation of our different content products, including our "how-to" articles, news, social media, webinars, Test Your Knowledge quizzes and more

As you have likely already noticed, our online makeover includes a new URL: www.chemengonline.com. Starting this month, the old URL will no longer redirect readers to our new site, so please start to use the new URL directly to find us.

In addition to the progress being made online, our print magazine is also undergoing a makeover that will be unveiled in 2015. We are modernizing our look to make it easier for you to find the information you need, and to make the print easier to read. Look for these updates, including our new logo, in an upcoming issue.

With all of these changes, one thing that remains constant is that our dedicated editorial staff continues to strive to bring our readers the same high-quality, relevant content that *Chemical Engineering* has been known for since its beginning in 1902.

In this issue, for example, our cover story discusses how to prepare more realistic project budgets by honing in on contingency costs (Improve Your Contingency Estimates for More Realistic Project Budgets, pp. 36–43). The Feature Report explores opportunities to improve energy efficiency and decrease energy consumption (Achieving Excellence in Energy Efficiency, pp. 44–49). Our Newsfront on electrochemistry (Winning with Electrochemistry, pp. 17–22) covers the latest advances in the electrochemical-based sectors of the chemical process industries (CPI), such as chlor-alkali, electrowinning and aluminum production. A second Newsfront looks at Advanced Coatings for New Applications (pp. 23–26). Our ever-popular Chementator section (pp. 11–16) brings you up-to-date on a variety of technology news, including a methane-to-methanol process, metals recovery, advances in battery development, a new method for making beryllium-aluminum alloys and more. And there is much more in this issue, as you can see.

As we move forward with our redesigned website and print magazine, we welcome your feedback. ■

Dorothy Lozowski, Editor in Chief

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Letters

SOCMA announces award winners

More than 28 member facilities will receive 2014 Performance Improvement Awards for their outstanding commitment to continuous improvement in environmental, health, safety and security (EHS&S) practices at the Society of Chemical Manufacturers and Affiliates (SOCMA) 93rd Annual Dinner on December 8 in New York.

The number of applicants for this year's awards was an all-time high for the Performance Improvement program. An outstanding group of companies has emerged from a month-long, double-blind selection process to receive a Gold, Silver or Bronze Performance Improvement Award for their successful EHS&S efforts. Educational Outreach and Sustainability Awards will be issued as well.

The 2014 Gold Performance Improvement Award goes to Baker Hughes Inc.'s Kilgore Blend Plant and Houston Blend Plant for their respective efforts in exceeding all standards set forth in the ChemStewards program.

Silver Performance Improvement Awards will be presented to 15 facilities showing excellence in one of the five ChemStewards Core Principles: stakeholder communications, product stewardship, EHS&S in planning and operations, employee training and engagement, and resource management and waste minimization.

Twenty five facilities will receive the Bronze Performance Improvement Award, which recognizes facilities maintaining strong EHS&S programs. A complete listing of award winners can be found on the SOCMA website, www.socma.org.

This year's Educational Outreach Award goes to Monument Chemical. The breadth of Monument's science education outreach efforts particularly stood out to award sponsor the Chemical Educational Foundation. In 2014, Monument volunteered at the MacDonald Intermediate School "STEMposium" in Ft. Knox, Ky., provided local teachers with free hands-on STEM activities, and sponsored the You Be The Chemist Challenge at the local, state and national levels.

Fairmount Santrol's Alpha Resins will be honored for the second year in a row with the ChemStewards Sustainability Award. The sustainable development culture reaches deep at Alpha Resins, and the company strives to nourish a stronger, more prosperous future for the company and surrounding communities. Alpha Resins sets specific goals and metrics to monitor sustainability. Their efforts have yielded — among other successes — an 84% reduction in landfill waste and methods to reuse solvents that have resulted in significant savings.

Society of Chemical Manufacturers and Affiliates
www.socma.org

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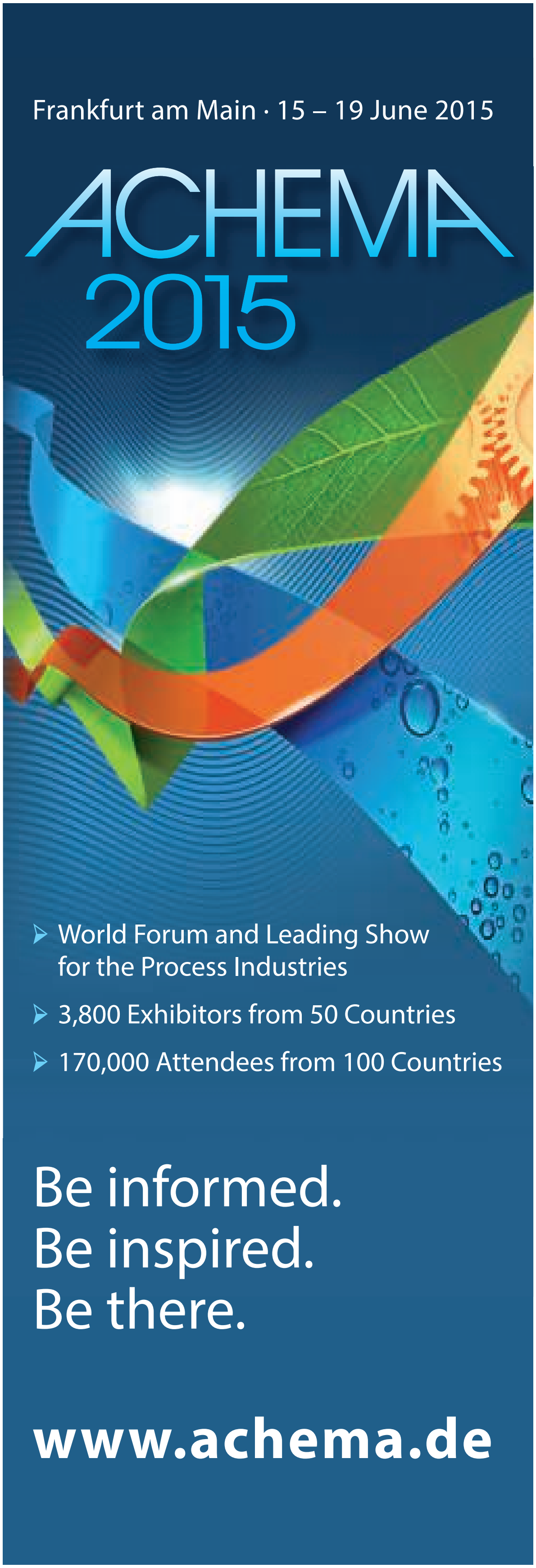

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Calendar

NORTH AMERICA

22nd Winter Fluorine Conference. American Chemical Soc., Div. of Fluorine Chemistry (Washington, D.C.). Phone: 800-227-5558; Web: acs.org
St. Pete Beach, Fla. **January 11–16, 2015**

5th Electric Energy Storage Conference. Marcus Evans North America (Chicago, Ill.). Phone: 312-894-6310; Web: marcusevans.com]
San Diego, Calif. **January 13–15, 2015**

2nd Annual Combined Cycle Operations & Maintenance. Marcus Evans North America (Chicago, Ill.). Phone: 312-894-6310; Web: marcusevans.com
Orlando, Fla. **January 21–23, 2015**

Informex 2015. Socma (Washington, D.C.). Phone: 609-865-6641; Web: informex.com
New Orleans, La. **February 3–5, 2015**

19th Annual Annual ARC Industry Forum. ARC Advisory Group (Dedham, Mass.). Phone: 781-471-1000; Web: arcweb.com
Orlando, Fla. **February 9–12, 2015**

Canadian Water Network: Connecting Water Resources 2015. University of Waterloo (Waterloo, Ont., Canada). Phone: 519-888-4567; Web: cwr2015.ca
Ottowa, Canada **March 10–12, 2015**

Phosphates 2015. CRU Experts in Mining, Metals and Fertilizers (London, U.K.). Phone: +44-20-7903-2444; Web: crugroup.com
Tampa, Fla. **March 23–25, 2015**

9th Annual ACEEE Energy Efficiency Finance Forum. American Council for an Energy-Efficient Economy (Washington, D.C.). Phone: 202-507-4000; Web: aceee.org
San Francisco, Calif. **May 31–June 2, 2015**

A&WMA 2015 Annual Conference & Exhibition. Air & Waste Management Assn. (Pittsburgh, Pa.). Phone: 412-904-6029; Web: awma.org
Raleigh, N.C. **June 22–25, 2015**

ACEEE Summer Study on Energy Efficiency in Industry. American Council for an Energy-Efficient Economy (Washington, D.C.). Phone: 202-507-4000; Web: aceee.org
Buffalo, N.Y. **August 4–6, 2015**

ACEEE National Conference on Energy Efficiency as a Resource. American Council for an Energy-Efficient Economy (Washington, D.C.). Phone: 202-507-4000; Web: aceee.org
Little Rock, Ark. **September 20–22, 2015**

(Continues)

Calendar

EUROPE

2nd European Sustainable Phosphorus Conference. European Sustainable Phosphorus Platform (ESPP; Brussels, Belgium). Web: phosphorusplatform.org
Berlin, Germany **March 5–6, 2015**

10th Status Seminar for Chemical Biology. Dechema e.V. (Frankfurt am Main, Germany). Phone: +49-69-7564-277; Web: dechema.de
Frankfurt am Main, Germany **January 21–23, 2015**

14th International Electronics Recycling Congress 2015. ICM AG (Birrwil, Switzerland). Phone: +41-62-785-1000; Web: icm.ch
Salzburg, Austria **January 21–23, 2015**

Interplastica 2015 — 18th International Trade Fair for Plastics and Rubber. Messe Düsseldorf (Düsseldorf, Germany); Phone: +49-211-4560-900; Web: interplastica.de
Moscow, Russia **January 27–30, 2015**

23rd European Biomass Conference and Exhibition. ETA-Florence Renewable Energies (Florence, Italy). Phone: +39-55-500-22-80; Web: eubce.com
Vienna, Austria **June 1–4, 2015**

10th European Congress of Chemical Engineering, 3rd European Congress of Applied Biotechnology, 5th European Process Intensification Conference. European Federation of Chemical Engineering (EFCE; Rugby, U.K.); Phone: +44-1788-534435; Web: ecce2015.eu
Nice, France **September 27–October 1, 2015**

ASIA & ELSEWHERE

ArabPlast 2015. Messe Düsseldorf North America (Chicago, Ill.); Phone: 312-781-5180; Web: mdna.com
Munich, Germany **January 27–30, 2015**

NanoTech 2015. ICS Convention Design, Nanotech Committee (Tokyo, Japan); Phone: +81-3-3219-3567; Web: nanotechexpo.jp
Tokyo, Japan **January 28–30, 2015**

International Exhibition on Chemical Engineering and 3W Expo 2015 International Exhibition on Water, Wastewater and Waste Treatment. TechnoBiz Group (Bangkok, Thailand). Phone: +66-2-933-0077; Web: cppe-expo.com
Bangkok, Thailand **January 29–31, 2015**

PlastIndia 2015. PlastIndia Foundation (Mumbai, India). Phone: +91-22-2683-2911-14; web: plastindia.org
New Delhi, India **February 5–10, 2015** ■

Suzanne Shelley

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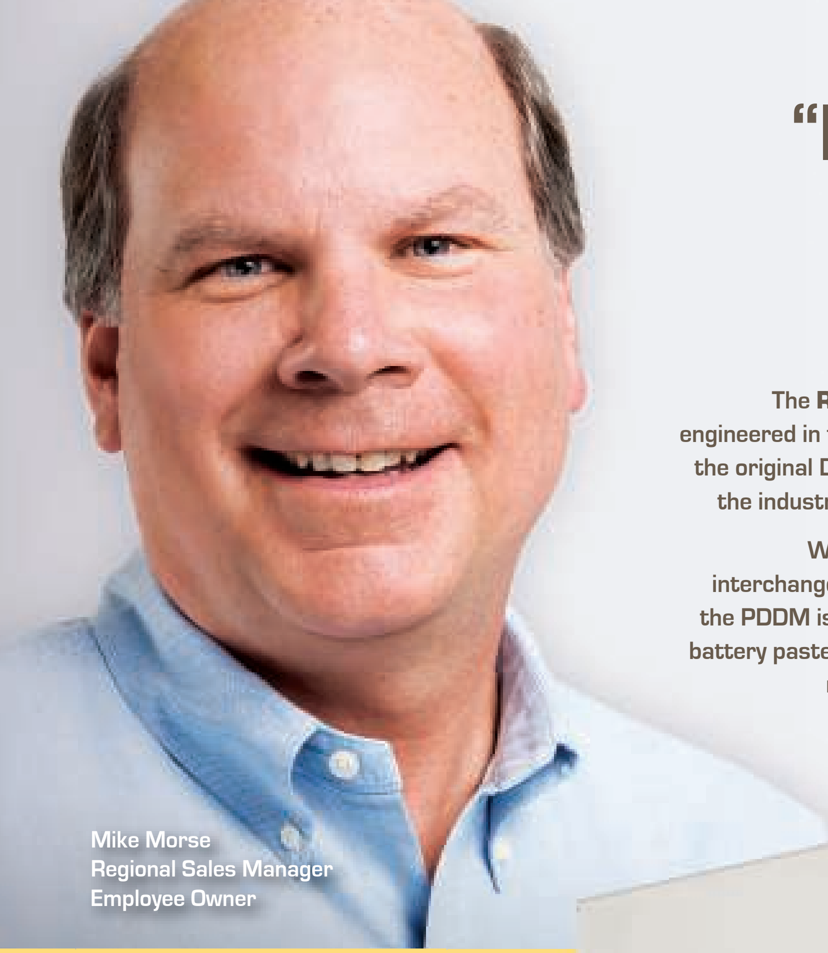

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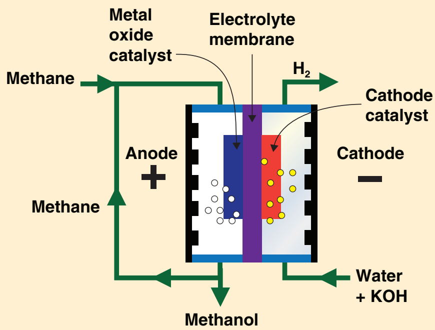
This methane-to-methanol process operates at low temperatures



A process that continuously produces methanol from methane is being developed by the Gas Technology Institute (GTI; Des Plaines, Ill.; www.gastechnology.org), with support from the U.S. Dept. of Energy's (Washington, D.C.) Advanced Research Projects Agency-Energy (ARPA-E). The process operates at about 80°C, and produces methanol and hydrogen with 100% carbon efficiency, says Chinbay Fan, GTI's R&D director.

Conventional routes to methanol involve steam reforming of methane into synthesis gas, followed by high-pressure methanol synthesis at pressures of 50–100 bars and temperatures of 200–300°C over a Cu/ZnO/alumina catalyst. Efficiencies of only 50–65% are achieved, depending on the waste-heat recovery, says Fan.

In contrast, GTI's process uses an electrochemically charged anode catalyst similar to the anode of a nickel-metal-hydride, or nickel-cadmium battery, explains Fan. The technique continuously generates NiO^+OH^- catalyst at the anode of an electrochemical cell (diagram). Methane gas flows through the cell and is efficiently oxidized to methanol with high selectivity. The catalyst is continuously regenerated at the anode (by the electrochemical charging process), and water is reduced to hydrogen gas at the cathode (net reaction: $CH_4 + H_2O \rightarrow CH_3OH + H_2$). In principle, the product H_2 could be fed to a fuel cell to provide some (as much as 50% or more) of the electrical power required by the electrochemical cell, says Fan.

The process has been scaled up from a single cell (30 cm^2 area) to a stack of ten cells (273 cm^2). The ARPA-E project is now in Phase II, and under license negotiation, says Fan. The process has the potential to monetize stranded natural gas that is commonly flared, and could reduce the production costs for methanol from \$2.80/gal to \$0.24/gal, he adds. Industrial production levels will be 100,000 gal/d, but there are "many hurdles that need to be conquered for on-well-site methanol production." (For more on electrochemistry, see Newsfront on pp. 17–22).

Carbon mineralization process monetizes CO_2 from fluegas

The Capitol SkyMine project in San Antonio, Tex. utilizes fluegas from an existing cement plant to manufacture salable chemicals while preventing the CO_2 from reaching the atmosphere.

Built by Skyonic Corp. (Austin, Tex.; www.skyonic.com), the project is said to be the world's first commercial-scale carbon capture and utilization facility, and is scheduled to be operational before the end of 2014.

Skyonic has developed two complementary processes that allow the production of sodium bicarbonate and hydrochloric acid using waste CO_2 from cement manufacturing. The first process is a modified chlor-alkali process that is optimized for the best return on energy, according to Stacy MacDiarmid, director of communications for Skyonic. The process involves electrolysis of brine solution to make NaOH, along with H_2 and Cl_2 gases. The H_2 and Cl_2 are combined to generate hydrochloric acid and bleach that can be sold. The NaOH is then moved into bubble columns for the second part of the process, where CO_2 is introduced to the columns. Through basic ionic chemistry, the NaOH reacts with the gaseous CO_2 to make Na_2CO_3 or $NaHCO_3$, which can also be sold. Prior to use, the fluegas is stripped of heavy metals, as well as NOx and SOx.

The processes developed by Skyonic are designed to retrofit onto existing stationary emitters of CO_2. The Capitol SkyMine facility will capture 75,000 ton/yr of CO_2, and from it, will generate 143,000 ton/yr of sodium bicarbonate and 183,000 ton/yr of HCl, says MacDiarmid. "Skyonic has found a viable way to do carbon capture profitably," she says. The Capitol SkyMine is expected to generate \$48 million in annual revenue and \$23 million in annual earnings.

Efficient distillation

Last month, Toyo Engineering Corp. (Toyo; Chiba, www.toyo-eng.co.jp) was awarded a contract for a distillation column in a methyl ethyl ketone (MEK) production plant of Maruzen Petrochemical Co. (Ichihara City, Chiba, Japan). The contract marks the first commercial application of an energy-saving distillation process called SuperHIDiC (heat-integrated distillation columns), which was patented in 2011.

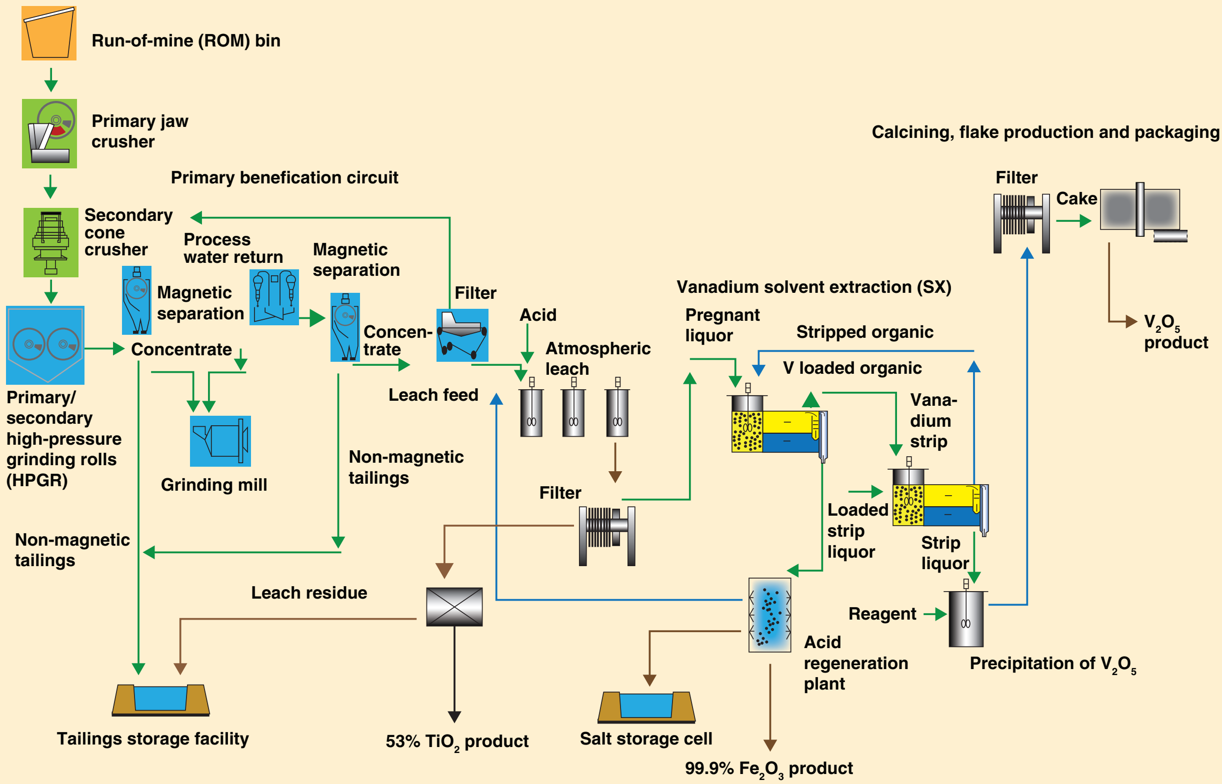
Advancing HIDiC and applying well-proven distillation and heat-transfer technologies, Toyo developed SuperHIDiC, a distillation system that enables 40–60% energy savings, in many cases, within the distillation process by providing optimal internal heat exchange. SuperHIDiC is co-licensed jointly with the National Institute of Advanced Industrial Science and Technology, and the engineering methodology was jointly developed with professor Shinji Hasebe at the Dept. of Chemical Engineering, Kyoto University (for more process details, see *Chem. Eng.*, January 2012, p. 10).

This antifreeze is edible

Since 2010, Kaneka Corp. (www.kaneka.co.jp) and Kansai University (both Osaka, Japan; www.kansai-u.ac.jp) have been collaborating on the development of special

(*Continues on p. 12*)

Note: For more information, circle the 3-digit number on p. 60, or use the website designation.



A new metals-recovery process moves to the pilot scale

Significant improvements to a process to extract vanadium, titanium and iron from the Mount Peake Vanadium-Titanium-Iron Project in the Northern Territory of Australia will be tested in a pilot plant now under construction and nearing completion. Results of the pilot-plant testing are expected to be available in the first quarter of 2015.

The project, 230 km north of Alice Springs, is wholly owned by TNG Limited (Perth, Western Australia; www.tngltd.com.au), and has a total resource estimate of 160 million tons with 0.28 wt.% vanadium (V_2O_5), 5 wt.% titanium (TiO_2), and 23 wt.% iron (Fe_2O_3).

TNG and local metallurgical company Mineral Engineering Technical Services (Perth; www.metsengineering.com) have developed the TIVAN hydrometallurgical process to extract the metals from the titanomagnetite ores that make up most of Australia's known vanadium deposits. The conventional pyrometallurgical process, involving salt roasting followed by water leaching, can pose environmental issues and is also capital intensive.

The alternative TIVAN process (flowsheet) uses the combined process of acid leaching, solvent extraction and stripping to selectively recover the metals. According to TNG, the concept of employing a hydrometallurgical route to process the vanadium titanomagnetite ore is the innovative part of the flowsheet. The company says there are no currently operating process plants that utilize a commercially viable route of extracting vanadium through a combination of leaching and solvent extraction. It says the benefit of this route is that hematite and TiO_2 are byproducts that can be sold to enhance the process' economic viability. The TIVAN process achieves higher recoveries and higher products purities: 99.0% V_2O_5, 99.9% Fe_2O_3, and up to 55% TiO_2.

Provisional site locations for a TIVAN refinery in Malaysia are under review.

antifreeze materials for applications in the food industry. In 2012, the group developed an antifreeze based on a protein derived from radish sprouts, which has since been adopted for use in noodles and over 50 food products and frozen foods. Now, the collaborators have developed a new antifreeze material that has superior properties to the predecessor, such as the suppression of ice-crystal formation.

The new antifreeze is based on xylomannan — a mixture of saccharides and a fatty acid found in the cell wall of the edible fungus, velvet shank. The extracted antifreeze has a molecular weight of 240,000–310,000 and a xylose-to-mannose ratio of 0.5. The researchers showed that the saccharide-based antifreeze is more stable than the protein-based antifreeze at high processing temperatures and over a wide pH range, thus making it suitable for a wider range of applications. They also confirmed that frying at more than 160°C did not influence the quality of fried foods.

Since October, Kaneka has been sending samples to potential users for

(*Continues on p. 14*)

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A new method for making beryllium-aluminum alloys expands accessibility

New techniques and equipment for manufacturing cast components made from beryllium-aluminum alloys can reduce the cost significantly, allowing the high-performance materials to be considered for a wide range of applications beyond their initial uses in the aerospace industry. Beryllium-aluminum alloys have several desirable properties, including light weight, high stiffness, low coefficient of thermal expansion and excellent thermal conductivity.

IBC Advanced Alloys Corp. (Vancouver, B.C.; www.ibcadvancedalloys.com) has developed an advanced vacuum-casting method that enables the casting of beryllium-aluminum parts at costs much lower than the traditional method of machining Be-Al pieces. IBC found a mixture of the two main metals, along with a host of alloying additives that enabled the material to be cast into specific near net shapes (reducing the need for surface finishing). The IBC casting method revives development work originally conducted in the mid-1990s by Ray White, now the president of IBC's Engineered Materials division. This research outlined a breakthrough pathway to net-shape casting of the Be-Al alloys.

"The ability to replace machined parts with cast parts dramatically alters the cost structure for high-performance Be-Al alloys," says Chris Huskamp, IBC executive vice president for business and technical development, "making the material accessible to a much wider range of possible applications, including many in industrial automation."

IBC is currently making Be-Al alloy products under the name Berelcast at its facility in Wilmington, Mass. Among the applications is a housing for a flight-critical electro-optical targeting system for the F-35 Lightning II military aircraft. The company estimates large market potential for Be-Al alloy castings, and says it is able to easily scale up its foundry operations to meet demand.

(*Continued from p. 12*)

testing. The company now plans to mass-produce the new antifreeze (up to several hundred tons per year) for applications such as frozen foods (fried and deep-fried) and yogurts.

Sweet surfactants

A new range of sugar-based surfactants for skin- and hair-care products has been commercialized by Clariant AG (Muttenz, Switzerland; www.clariant.com). Tradenamed GlucoTain, the surfactants are based on glucose and natural oils, and are said to offer enhanced sensory benefits without compromising cleansing performance. The product range offers formulators the possibility for creating products that are free of sulfates, cocamidopropylbetaine (CAPB), ethylene oxide (EO) and polyethylene glycol (PEG).

Explosion-proof enclosure for world's largest gas-to-urea plant

Protective-enclosure maker Intertec Inc. (Sarnia, Ont.; www.intertec.info) is building a unique, explosion-proof, pressurized shelter for a granulated urea warehouse at what will be the world's largest, single-stream, gas-to-urea plant in Nigeria.

The three-section enclosure protects personnel and electronics from potentially explosive dust generated from the movement of bulk urea granules. The walls, ceilings and floors of the shelter's three areas are made from Intertec's proprietary glass-reinforced polyester (GRP) material. "The GRP enclosure material has anti-static properties to reduce the risk of sparking a dust explosion," explains Martin Hess, Intertec CEO, "and is also fire-retardant, impact-resistant and has a chemical-resistant gel coat."

Intertec has developed a unique manufacturing process that allows construction of large (up to 12 m long) panels of GRP material that comply with user-defined dimensions and specifications. The mating panel edges use chemically bonded overlapping joints that provide excellent mechanical strength without the need for penetrative fittings, says the company.

The enclosure in the Nigeria fertilizer plant was designed to be airtight, including an airlock system for entry and exit that maintains positive air pressure to prevent ingress of dust, Hess says, and also reduces air leakage, so the costs for compressing air are lowered.

The fertilizer plant, due to be completed at the end of 2015, will produce 4,000 ton/d of urea.

These batteries charge faster, last longer

A new lithium-ion battery that can be recharged in only two minutes — 20 times faster than with current technology — has been developed by scientists from Nanyang Technological University (Singapore; www.ntu.edu.sg). The battery will also have a lifespan of more than 20 yr, with the ability to undergo 10,000 charging cycles — 20 times more than today's batteries.

The scientists replaced the traditional graphite anode used in Li-ion batteries with a new gel material made from TiO_2, which is naturally found in a spherical shape. They developed a simple method — conceived by associate professor Chen Xiaodong from the university's School of Materials Science and Engineering — to transform the TiO_2 particles into tiny, extremely thin nanotubes. It is this nanostructure that helps speed up the chemical reactions in the new battery, leading to superfast charging.

The scientists now plan to move to the proof-of-concept stage and build a large-scale battery prototype. Their patented technology is currently being licensed to a company, and Chen expects that the batteries will hit the market in about two years. The technology will allow electric vehicles to increase their range with only five minutes of charging time, which is comparable to the time needed to refuel present-day cars, says Chen.

Commercial debut for a new bioleaching process

Division Radomiro Tomic of Codelco (Codelco Corporación Nacional del Cobre de Chile; Santiago; www.codelco.www) is adopting a bioleaching process to recover copper from low-grade ores. The process was developed by BioSigma S.A. — a joint venture (JV) of JX Nippon Mining & Metal Corp. (Tokyo, Japan; www.nmm.jx-group.co.jp) and Codelco — and is the culmination of 12 years of development work by the JV. BioSigma's process will enable Radomiro Tomic to produce copper from sulfide ores that have previously not been considered reserves, because the Cu could not be economically recovered using conventional solvent-extraction/electrowinning (SX/EW) plants.

As in conventional bioleaching, the process starts with the production of biomass in bioreactors to produce different solutions enriched with specific bacteria and other microorganisms. Ore heaps are then continuously irrigated with these solutions, and the bacteria dissolve iron and sulfur, and release copper into the solution. At the bottom of the heap, the so-called pregnant leach solution (PLS) is collected and stored in a pond, where it can then be treated by the SX/EW plant to produce high purity Cu.

The process was tested for a year on two heaps of low-grade ore, each containing about 25,000 tons of ore, with an average grade of 0.4% Cu. More than 70% of the copper contained in these ores was in the form of primary sulfides (chalcopyrite and bornite). BioSigma's process is said to recover 30–50% more copper than other bioleaching systems available, and at a rate that is three times faster.

The bioleaching process is being integrated into Radomiro Tomic's production plans this year, starting with a project to treat 3.6 million tons of low-grade sulfide ore, and 5.0 million tons of low-grade ore by 2015.

Coating for extremes

A coating that can protect turbine-engine and waste-incinerator components against heat and oxidation has been developed by researchers at the Fraunhofer Institute for Chemical Technology (ICT; Pfinztal, Germany; www.ict.fraunhofer.de). The coating consists of an outer topcoat made from hollow, aluminum-oxide spheres. The spheres contain gas, so when the outer side is exposed to high (1,000°C) temperatures, the spheres reduce the temperature on the inner side to below 600°C.

The coating process is said to be an adaptation of conventional coating processes used to prevent the oxidation of metal components. The new coating retains this oxidation protection, with the additional benefit of thermal insulation, says ICT. The researchers have also refined the coating process to produce layers of the desired thickness (for more on coatings, see Newsfront on pp. 23–26).

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Synthesizing omega-3 lipids from waste gases and algae

A collaboration between LanzaTech (Skokie, Ill.; www.lanzatech.com) and the IOC-DBT Center for Advanced Bio-Energy Research (Faridabad, India; www.iocl.com) has led to a carbon-capturing process that synthesizes omega-3 lipids in algae. Via a continuous fermentation step that takes place in a specialized gas-fermentation reactor, proprietary microbes convert captured waste gases — CO_2 and H_2 — into acetate. Any CO_2 source can be used, but the process works best with highly concentrated CO_2 (greater than 50%), since blending with H_2 is required. Acetate is the only metabolite produced during the fermentation. The resulting acetate-rich broth is then fed to algae, which are housed in a scalable, industry-standard bioreactor, where the acetate is converted into fatty acids.

Once the algae have grown very rich in omega-3 fatty acids, there are two potential end products for this process: the algae can be dried and used as a fish-meal substitute in the aquaculture industry, or the lipid-rich algal oil can be extracted and purified, resulting in saleable omega-3 lipid products. The group is currently working to identify the best commercial lipid-extraction method to be applied in this process.

The process has been demonstrated at bench scale at IOC-DBT's facility in Faridabad, and construction of a continuous pilot plant is planned for next year, most likely also located in Faridabad. Once the process is commercialized, LanzaTech will serve as the sole licensor of the integrated technology. The diversity of the end products is key to the process' success, the company says, emphasizing the significance of the ability to transform abundant waste gases into valuable omega-3 products for both the worldwide food and energy industries. ■

H_2 and CO_2 from APG

Last month, Chiyoda Corp. (Yokohama; www.chiyoda-corp.com) and Mitsubishi Heavy Industries Ltd. (Tokyo, both Japan; www.mhi.com) received approval in principle (AIP) for a jointly developed floating production, storage and offloading (FPSO) facility for the production of H_2 and CO_2 from associated petroleum gas (APG).

The H_2/CO_2 FPSO will perform steam reforming of APG that is generated by offshore plants above subsea oil fields. Simultaneously, the process will convert the H_2 into methylcyclohexane via an organic chemical hydride method. As a result, the H_2 is essentially stored as methylcyclohexane — a liquid form at ambient temperature and pressure. This so-called Sera hydrogen can then be transported to shore, where the H_2 is extracted by a dehydrogenation process developed by Chiyoda, and supplied to existing infrastructures. The CO_2 co-product from the reformer will be used in enhanced-oil recovery (EOR). Chiyoda says that this will be the world's first FPSO to incorporate the new H_2/CO_2 concept. ❏

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WINNING WITH ELECTROCHEMISTRY

New electrode designs and process technology promise to reduce energy costs in traditional processes


Outotec

FIGURE 1. Shown here is Outotec's Cu electrowinning (EW) anode. EW plants utilize hundreds to thousands of electrodes to recover high-purity metals

These days, the term electrochemistry has become almost synonymous with advanced batteries and energy-storage devices, and considerable R&D efforts abound for both batteries (*Chem. Eng.*, October 2013, pp. 17–23) and energy storage (*Chem. Eng*., December 2011, pp. 19–23). Nevertheless, traditional, century-old electrochemical-based sectors of the chemical process industries (CPI) — chlor-alkali, electrowinning (EW) and primary aluminum production — have not been idle bystanders. That's because these traditional, extremely important sectors require large amounts of electrical energy for making their corresponding products.

At the same time, demand continues to grow for base elements. For example, chlorine is used in many CPI applications, including agrochemicals, pharmaceuticals, plastics, water treatment and many more. Base metals, such as copper and zinc, continue to be important for cables, piping and packaging. And light metals, such as aluminum and magnesium, are of growing importance in lightweight constructions.

To meet these increasing demands, and to counter ever-growing energy costs, new materials (for electrodes) and process technology are being developed to reduce energy consumption in these traditional electrochemical industries. Additional benefits, such as increased productivity and improved environmental performance, are also being realized. Some of these recent developments — certainly not all — are presented here.

Electrowinning

Electrowinning (EW) is the main method used in the mining industry to recover pure metal products (Cu, Zn and others) after the metals have been extracted from ores. Depending on the metal, the product is plated onto the cathode of an electrochemical cell, and either oxygen (sulfate-based Cu, EW for instance) or chlorine (chloride-based Cu EW) is produced at the anode. As in the chlor-alkali process, EW is energy intensive, requiring large amounts of electricity.

Reducing operating costs of the EW processes was one of the driving forces for the development of coated titanium anodes that are now commercially available from Outotec Oyj (Espoo, Finland; www.outotec.com). The anodes were developed by Republic Alternative Technologies (Strongville, Ohio) — just acquired by Outotec in April of this year — in collaboration with a large U.S. copper producer. In addition to reducing the energy consumption in the EW process, the coated Ti anodes contain no lead. The presence of lead in conventional Pb-Ca-Sn anodes leads to number of problems, both environmental (sludge formation) and product quality (lead contamination at the cathode).

Outotec's anodes (Figure 1) consist of amorphous nanoparticles of metal oxides (Ir or Ru, and Ta) coated onto a Ti screen, explains Tim Robinson, head of Outotec's Coated Ti Anode business, in Phoenix. The fully amorphous coating technology is licensed from Doshisha University (Kyoto, Japan; www.doshisha.ac.jp), where the technology was first developed by professor Masatsugu Morimitsu. In the EW cell, the coating on the anode lowers the O_2 overvoltage compared to lead-based anodes, thereby reducing the overall cell voltage by up to 20% in the case of a sulfate-based Cu EW process, says Robinson.

The first commercial demonstration of the alternative anodes has been running since 2008 at a solvent-extraction, electrowinning (SXEW) copper plant in New Mexico. The plant also was able to eliminate the addition of cobalt sulfate to the electrolyte solution, which had been needed to prevent corrosion of the lead anodes. Also, cell cleaning for the removal of lead sludge was no longer required. And lead concentrations at the cathode decreased to below detection limits, Robinson says.

Since the N.M. project, Outotec's Ti anodes have been installed at Cu EW facilities in Ariz. (2010) and Chile (2011) — the plant in Chile has 30,000 anodes. Two Cu EW plants in Northern Mexico are converting to the new anodes this year in Sonora province. Outotec is also working closely with Glencore Kristiansand on the potential modernization of the Cu EW plant in Norway with the demonstration of the coated Ti anode technology and a focus on cell energy reduction, and lead-free copper product at the cathode, says Robinson.

Meanwhile, in 2010, Industrie De Nora S.p.A. (Milan, Italy; www.denora.com) started a program to develop new anodes for Cu EW, based on its DSA (dimensionally stable anode) technology. "We are now at the advanced phase of development," says Luciano Iacopetti, R&D officer at De Nora. The new anode offers an energy savings of up to 15% compared to conventional lead-alloy anodes, he says.

The company already has produced and sold DSA anodes for Ni EW from a chlorine leach process since 1972, in addition to anodes and patented coating formulation applications for the production of Cu foils and printed circuit-boards used in the electronics industry. "Cu EW is the ultimate challenge," explains Iacopetti, "because reliability, stability and energy efficiency are not only important, but must be proven."

Drawing on its 40 years experience in coating Ti anodes, De Nora has developed a novel mixed-metal-oxides (MMO) coating with improved catalytic activity gained by modifying the crystalline lattice and reducing the crystalline size, without changing the thermal-production conditions used in the coating process, explains Iacopetti.

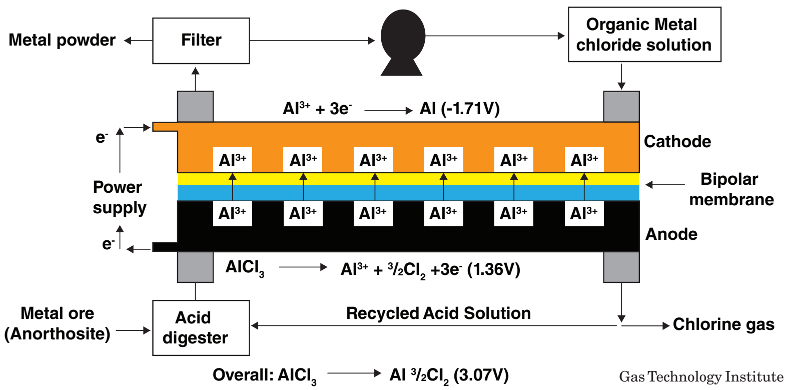
De Nora is currently conducting field demonstrations of its new anode technology, using an industrial tank cell (such cells typically contain 60–100 anodes), and anodes with an area of 2 m^2. Already the anodes have been shown to have an average voltage savings of 300 mV over Pb-alloy anodes, and no drift in voltage observed, even after one year of operation in the industrial electrolyte, says Iacopetti. The goal

A PUSH FOR ELECTROCHEMISTRY

Last month, the first meeting of the Executive Board took place (after press time) for the new industrial consortium, Electrochemical Pathway for Sustainable Manufacturing (EPSuM)— an 18-month project supported under the Advanced Manufacturing Technology Consortia (AMTech) Program of the National Institute of Standards and Technology (NIST; Gaithersburg, Md.; www.nist.gov). The executive committee has members from Bayer MaterialScience, The Dow Chemical Company and Faraday Technology, Inc. as well as the president of the Electrochemical Society, and is headed by Gerardine Botte, the Russ Professor of Chemical Engineering and Biomolecular Engineering at Ohio University (Athens; www.ohio.edu), the founder of the university's Center for Electrochemical Engineering Research, and the founder and director of the National Science Foundations's Center for Electrochemical Processes and Technology (CEProTECH; www.ceprotech.com). In addition to the executive committee, the following companies are part of the EPSuM advisory board: Dupont, Owens Corning, IBM, Valvoline, IGS Energy, De Nora, Archer Daniels Midland, PolyOne, GrapTech International Holdings, Inc., and Sherwin Williams.

The newly forming consortia aims to develop a technology roadmap to support, sustain and enhance U.S. manufacturing capacity in the CPI through innovative processes that utilize electrochemical science and technology. The goal is to determine what the critical needs in industry are, and prioritize where the R&D and funding should go, explains Botte. Except for batteries, it seems that many in the U.S. have abandoned electrochemistry, she laments. "We want to put electrosynthesis back on the map."

The first EPSuM workshop takes place December 16 at the Sherwin Williams R&D Center in Cleveland (for more information, see www.ceprotech.com/epsum-workshop). ❑



Gas Technology Institute

FIGURE 2. By avoiding the use of molten salts, this Al-production process can operate at room temperature, thereby slashing energy consumption

is to achieve an operating life of five years of stable operation without increasing cell voltage and loss of efficiency, which is better than traditional lead anodes, he says.

Meanwhile, in February 2014, Electrometals Technologies, Ltd. (Gold Coast, Queensland, Australia; www.electrometals.com) announced plans to design larger "emew" cells that will lower the installed cost, double production capacity per cell, and nearly triple the productive footprint of its standard cells. Unlike the planar electrodes used in conventional EW cells, emew cells use concentric cylindrical electrodes. This design is said to "significantly" enhance mass transfer, thereby improving cell efficiency.

Primary aluminum production

Today, aluminum continues to be manufactured by the 19th-century Hall-Héroult process, whereby alumina (Al_2O_3) is dissolved in molten salts and electrolyzed. As such, the process is very energy intensive, both because of the high temperatures involved and the electricity needed to run the electrolyzer. Besides high energy costs, the high operating costs are compounded because the process uses large amounts of graphite or coke that are used for the anodes, and which are consumed during the electrolysis to make CO_2 — in itself another drawback of primary Al production.

A different approach to primary Al production is being developed by the Gas Technology Institute (GTI; Des Plaines, Ill.; www.gastechnology.org), with support from the U.S. Dept. of Energy's (Washington, D.C.; www.energy.gov) Advanced Research Projects Agency-Energy (ARPA-E; www.arpa-e.energy.gov). GTI's project is one of about 18 in ARPA-E's Modern Electro/Thermochemical Advances in Light Metal Systems (METALS) program, which aims to find cost-effective and energy-efficient manufacturing techniques to process and recycle light metals (Al, Ti, Mg) for lightweight vehicles and aircraft.

GTI is developing a continuously operating cell (Figure 2) that produces Al powder with potential cost savings of 44% compared to the conventional Hall-Héroult process. Conventional Al production is done by pumping huge electrical currents into a vat of molten aluminum dissolved in mineral salts at up to 2,000°F. In contrast, GTI's DEEE technology (dual electrolyte extraction electro-refinery) operates at nearly room temperature using recyclable solvents to dissolve the ore. Liquid-liquid extraction is used with the aid of electro-osmotic drag in an electrolyzer cell. Al^{+3} ions in an acid solution in the cathode cell migrate through a bipolar membrane to the anode, where they are reduced to Al metal.

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(to be completed at the end of this month), several milestones have been achieved, says Chinbay Fan, GTI's R&D director. Using a stack of 3–5 cells with 100 cm^2 area, a Faradaic efficiency (current efficiency) of 83% has been observed, with production of up to 14 g/h of Al powder of >98% purity. Negotiations are now underway for Phase II, which will aim to further optimize the process and scale it up.

Meanwhile, Alcoa (Pittsburgh, Pa.; www.alcoa.com) is also developing a new electrolytic cell to improve the efficiency of aluminum production with support from the ARPA-E METALS program. The three-year project, which started last March, aims to recover the large amounts of waste heat lost in conventional cells by improving electrode design and integrating a heat exchanger into the wall of a cell. Normally the electrodes in Al smelters are horizontal. Alcoa plans to angle its cathode, which will have the effect of increasing surface area of the cell and shortening the distance between cathode and anode. The cathode will also be protected by highly conductive and durable ceramic plates. These changes will combine to increase the output from a given cell and enable reduced energy usage, says ARPA. Alcoa's design also integrates a molten glass or salt heat exchanger to capture and reuse waste heat within the cell walls when needed, and reduce global peak energy demand. Adoption of a new design could lead to an energy reduction of 0.1 quad/yr across the entire U.S. aluminum industry, says ARPA. [A quad is a unit of energy equal to 10^{15} (a short-scale quadrillion) Btu. or 1.055 × 10^{18} joules (1.055 exajoules or EJ) in SI units.]

Chlor-alkali

The energy-intensive chlor-alkali sector continues the slow process of replacing mercury-cells and asbestos-based diaphragm cells to membrane technology (*Chem. Eng.*, February 2001, pp. 31–33). As a result, chlor-alkali plants are not only "greener," they are consuming less energy. For example, Ashta Chemicals Inc. announced last June that it selected Ineos Technologies' (Rolle, Switzerland; www.ineos.com) BiChlor bipolar electrolyzers to replace mercury-cell technology that has been operating since the 1960s in Astabula, Ohio. By converting to membrane cell technology, Ashta Chemicals says it will reduce electricity consumption by about 20%.

Meanwhile, adoption of possibly the most significant breakthrough in chlor-alkali technology is slowly being realized. The so-called oxygen-depolarized cathodes (ODC) was developed by Bayer AG (now Bayer MaterialScience; Leverkusen, Germany; www.materi-

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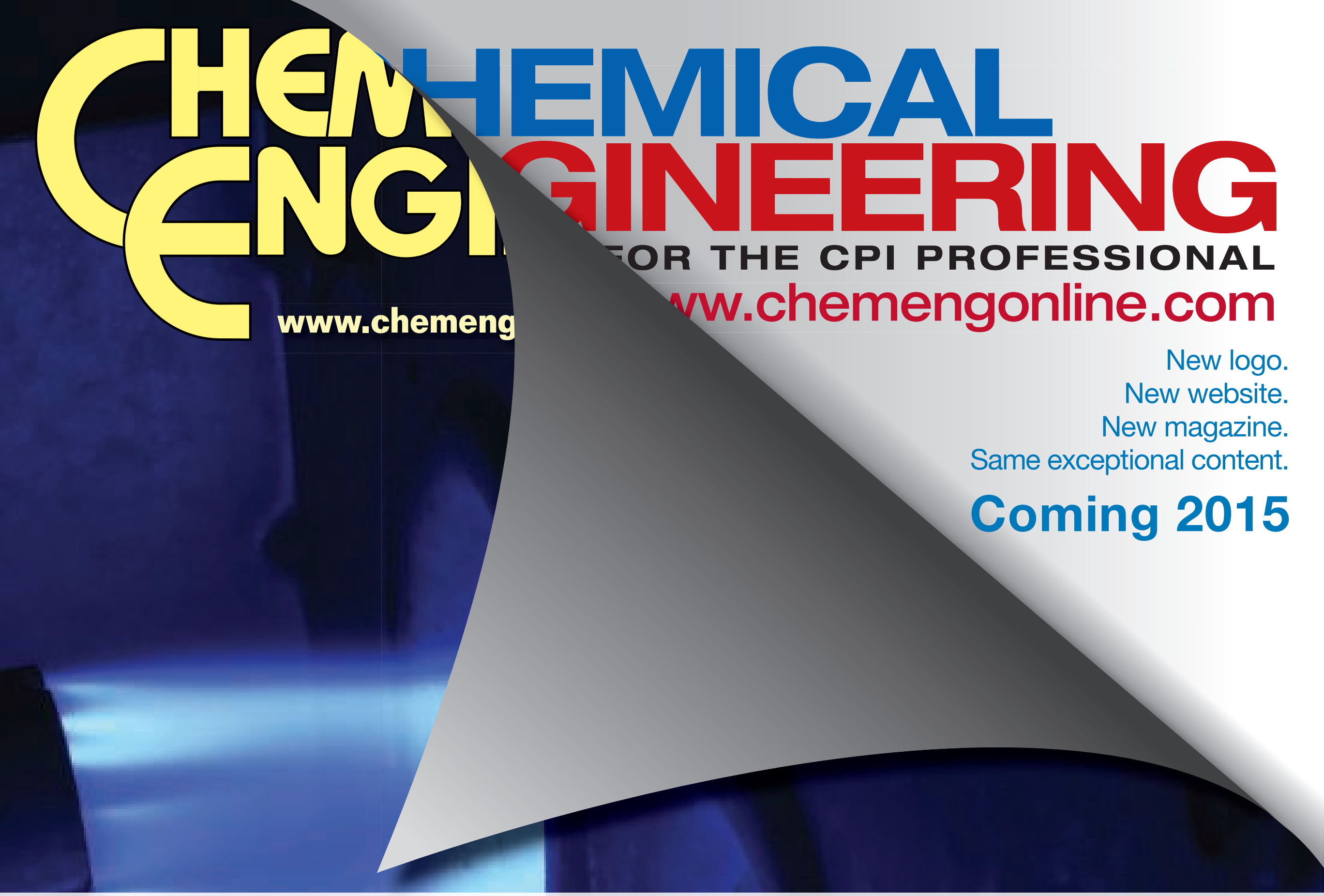

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alscience.bayer.com), De Nora, and Uhde (now ThyssenKrupp Electrolysis GmbH, a 100% subsidiary of ThyssenKrupp Industrial Solutions AG; Dortmund, Germany; www.thyssenkruppindustrial-solutions.com). When ODC is introduced into a chlor-alkali plant, H_2 is no longer produced as a byproduct in the electrolyzer, and the operating voltage is reduced from about 3 V to 2 V. As a result, energy consumption for Cl_2 production is reduced by about 30%, says Bayer Material Sciences (for more details, see *Chem. Eng.*, May 2007, pp. 50–55).

The commercial application of ODC technology started with hydrogen-chloride electrolysis. The recovery of Cl_2 from electrolysis was initially developed in the late 1990s by De Nora and Uhdenora — a joint-venture (JV) between ThyssenKrupp Electrolysis and Industrie De Nora. Thanks to the collaboration with Bayer, the first industrial-scale facility to use ODC was demonstrated at Bayer's Brunsbüttel, Germany site (*Chem. Eng.*, March 2004, p. 17). Since then, Bayer has implemented ODC for HCl electrolysis in large sites [30,000 metric-ton per year (m.t./yr)] in Caojing (near Shanghai), China.

The ODC technology for the chlor-alkali process was first commercialized in June 2013 by Uhdenora. In February 2014, Uhdenora received its first order for this ODC technology, and signed a contract with Befar Group Co. for the construction of an 80,000-m.t./yr caustic soda plant at Binzhou City, China. The project is being implemented in two phases: the first phase, which is to be commissioned in the 2nd quarter of 2015, will have a capacity of 40,000 m.t./yr; and the second phase will follow shortly thereafter.

Under the JV Uhdenora, ThyssenKrupp Industrial Solutions and De Nora have already been cooperating for several years in licensing various electrolysis processes, says Luca Buonerba, chief marketing and business development officer, Industrie De Nora. In November 2013 both companies agreed to fully combine their engineering, procurement and construction activities for electrolysis plants — as well as those of Chlorine Engineers Corp. (Tokyo, Japan; www.chlorine-eng.co.jp), which became a 100%-owned subsidiary of Industrie De Nora in 2012 — in a planned new JV under the name ThyssenKrupp Uhde Chlorine Engineers. This will enable both partners to expand their technological platforms and move closer to customers through increased global presence, says De Nora's Buonerba. The agreement is subject to approval by the relevant antitrust authorities. ■

Gerald Ondrey

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ADVANCED COATINGS FOR NEW APPLICATIONS

New formulations allow industries to evolve, and reduce labor costs and environmental concerns

Changing markets and new applications are putting more demands on the protective coatings industry than ever before. While developing environmentally friendlier and less labor-intensive corrosion- and chemical-resistant paints and coatings is always a major goal, new formulations are needed to address the coating challenges presented by today's changing chemical process industries (CPI), as well as modern construction and other engineering capabilities.

"Reduction of VOCs [volatile organic compounds] and labor costs will always be sought after goals in the protective coatings industry, but we are beginning to see additional needs emerge as there is an increase in operating temperatures in many applications, especially in oil-and-gas and chemical processing, as well as more and more astounding feats of engineering cropping up," says Jerry Witucki, associate coating scientist with Dow Corning (Midland, Mich.; www.dowcorning.com).

New applications

"Enormous structures, such as mega skyscrapers and wind turbine farms, especially those in the middle of the ocean, not only have the initial challenging performance requirements, but also, the owners don't want to send someone up or out to repaint them," explains Witucki. "They need a protective coating that will last for decades, which is placing demands on coatings that simply haven't existed in the past."

In addition, he says, even everyday applications, such as chemical-processing equipment and bridges require more from coatings than ever before because shutting down a process or bridge to paint is becoming cost prohibitive in today's competitive economic environment. And, in many industries, temperatures are increasing, which piles on additional demands. "People want to operate their lines faster, so they heat up the oven to higher temperatures or, for better emission control, they may turn up the heat in a catalytic converter to ensure complete combustion, so they are looking for coatings that provide longer-lasting performance at higher temperatures," says Witucki.

"It costs a lot in lost production time and labor to have someone repaint, so between labor costs, shut down costs and environmental costs, the actual cost of the paint or coating is no longer the primary consideration for the end user," says Witucki. "They are willing to absorb the cost of a more expensive paint if it means it won't have to be applied as often."

He says, in the past, organic resins were the "go-to" coating for many of these applications, but with more demanding criteria, the existing formulations were not working as well, so coatings manufacturers started seeking new ingredients and additives that would boost the durability and life of their coatings.

Dow Corning, says Witucki, strives to create materials, such as silicone-organic hybrids, which possess greater thermal stability and better chemical resistance when added to coating formulations. "We've seen a steady increase in the number of U.S. patents using silicone-organic hybrids, to the point where 10% of all U.S. paint patents as of 2013 incorporated silicone-organic hybrid technology," notes Witucki.

FIGURE 1. SiVance's C1008 is a silicone curative that improves the durable flexibility of epoxy polysiloxane protective topcoats in marine and infrastructure applications

Jeff Jones, business development director with SiVance, LLC, a subsidiary of Milliken & Co. (Gainesville, Fla.; www.sivancellc.com), agrees that new ingredients are the key to developing better coatings for changing applications. "In the oil-and-gas industry, especially, they are seeking protective coatings that are more durable to higher temperatures, higher pressures and nastier mixes of chemicals at those higher temperatures than ever before," he says. "In these applications, they were finding a lot of the coatings they had been using for tank and pipe linings were just not durable enough for the higher temperatures and new mixtures of chemicals they are seeing today." One of the reasons is that the products resulting from hydraulic fracturing are very different and more corrosive than the traditional products. Another example is in deep-sea oil drilling where, as the oil-and-gas industry is forced to dig deeper, the environment becomes more harsh. "They need coatings that perform better under these new conditions," says Jones.

As an ingredient supplier to the protective coatings industry, he says, it was SiVance's job to determine what was causing failure under new operating conditions and adjust the chemistry accordingly to avoid those failures. The company started by examining the issues exhibited by structural coatings.

"We are a silicones producer and we realized that many of the protective coatings for structural applications were epoxy-based because epoxy provides excellent adhesion and corrosion resistance at a low cost. However, silicones are outstanding for weatherability, flexibility and thermal stability, which are needed to increase the durability of protective coatings used in these applications. We decided to combine the best of both worlds and devised a silicone material that coatings producers could easily formulate into their existing epoxy system," says Jones. "What we developed allows them to create an epoxy that acts a bit like a silicone to give their coatings a boost in the properties that can help increase durability."

The first product introduced by SiVance was its C1008 (Figure 1), a silicone curative that improves the durable flexibility of epoxy polysiloxane protective topcoats in marine and infrastructure applications, without sacrificing weatherability. The curative solves a major challenge common to epoxy polysiloxanes: brittleness and cracking that can develop over time as the coating continues to cure.

The curative is designed for use in coatings applied to piping, bridges, wind turbines, offshore platforms, tank exteriors, structural steel and heavy equipment. It uses a proprietary molecular structure that provides enhanced compatibility in epoxy systems. The product is fully miscible with hydrogenated bisphenol-A-epoxy resins. The compatibility of C1008 in other epoxy resins is possible with the

Source: Tnemec

FIGURE 2. Series 391 Tank Armor from Tnemec is a chemical-resistant formulation for use in severe chemical-immersion environments

use of solvents or reactive diluents.

Jones says the company is preparing to launch a second product that will provide more compatibility with the epoxy coatings most commonly used in the oil-and-gas industry where the need for higher-performing coatings continues to grow due to the challenges presented by hydraulic fracturing and deep-sea oil drilling.

Good for the environment

Formulators are also faced with the challenge of providing more durable protective coatings for today's oil-and-gas industry that are more environmentally friendly, says Gary Zinn, director of sales — industrial markets, with Tnemec Co. (Kansas City, Mo.; www.tnemec.com). "In the past, a lot of the tank-lining materials contained solvents and VOCs. Today's technology needs to be 100% solids with little to no VOCs or solvents, yet still provide excellent transfer, high-build characteristics and protection from today's heavier and higher-sulfur-content crude."

In response, Tnemec, introduced a 100% solids epoxy liner for use in transport tanks containing chemical blends or acids used in hydraulic fracturing (Figure 2). Series 391 Tank Armor is a chemical-resistant formulation for use in severe chemical-immersion environments. "Series 391 Tank Armor meets the requirements of customers in the oil and gas service industries, such as rapid return to service, one-coat application, fast-cure, high-build capabilities, ease of application and physical properties for long-term durability," says Zinn. "It also offers excellent corrosion protection against hydrochloric acid and selected chemical combinations, along with toluene and xylene blends, which may also be used for well-service treatment."

Environmental friendliness isn't just a trend in the oil-and-gas industry. It is a requirement in almost every industry, and, as laws and regulations become more stringent, the protective coatings industry is responding to these needs with kinder, gentler products and application processes.

One such development is the Co-Cure coating process from Henkel Corp. (Rocky Hill, Conn.; www.henkelna.com). This unique process reduces the environmental impact because it layers Henkel's coatings with a topcoat and "co-cures" them together in a single oven, which reduces energy consumption and waste-treatment costs.

"The chemistry in the first layer allows us to dehydrate the coating without having the need to fully cure it at high temperatures for long durations," explains Omar Abu-Shanab, technical director with Henkel. "The second layer is applied and both layers are Co-Cured and chemically crosslinked in a single oven."

"This process is unique to our coatings," says Mike Berger, business development manager with Henkel. "Many other coatings require users to wholly cure the primer before the top coat can be applied, which requires two ovens and much longer durations of time at higher temperatures. In new applications, end users can employ a shorter oven, which results in lower equipment costs. In existing lines, they can turn down the oven temperature and reduce the time and save energy."

The Co-Cure process can be used with Bonderite M-PP 930 Autodeposition Coating. The coating delivers enhanced corrosion performance in applications such as vehicle frames and chassis components, construction equipment and appliances (Figure 3). The environmentally sustainable coating contains no toxic heavy metals and is very low in VOCs. In addition to its environmentally friendly profile and application

Source: Henkel

FIGURE 3. Bonderite M-PP 930 Autodeposition Coating from Henkel delivers enhanced corrosion performance in applications such as vehicle frames and chassis components

process, the coating was developed for use on difficult-to-coat reactive substrates where traditional protectants could not provide a uniform coating, which often resulted in exposure to corrosion through microscopic pinholes. Bonderite M-PP 930C addresses issues applicators face when coating cast substrate by eliminating surface voids and outgassing, which contribute to improved corrosion properties. Because Bonderite M-PP 930 provides uniform coverage with lower maintenance requirements — there is no

Source: Cortec

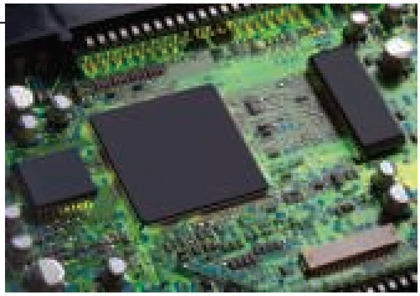

FIGURE 4. Cortec's Ecosonic Conformal Coating powered by Nano-VpCI for use as a circuit-board conformal coating combines moisture-intrusion prevention and corrosion resistance with the company's Vapor-phase Corrosion Inhibitor (VpCI) technology

ultrafiltration, no rectifiers, no electrodes and fewer stages — the coating is expected to last 5 to 10 years under extreme corrosion conditions, says Henkel's Abu-Shanab. This combination of the shorter cure time and the reduction in maintenance results in lower labor costs, says Berger, which is another demand on today's protective coatings.

Cortec Corp. (St. Paul, Minn.; www.corteccvci.com) also saw an opportunity to improve several pro-

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tective coatings by making them both more environmentally friendly and less labor intensive. For example, the Ecosonic Conformal Coating powered by Nano-VpCI for use as a circuit-board conformal coating combines moisture-intrusion prevention and corrosion resistance with the company's Vapor-phase Corrosion Inhibitor (VpCI) technology (Figure 4). It contains an optical identifier visible with ultraviolet light, assuring rapid and effective visual confirmation of proper coating on surfaces. The coating is VOC-free, fast-drying and a single-component formulation, which is easier to use than two-component coatings, eliminating the need for special metering and mixing equipment.

Cortec saw another opportunity to help customers reduce labor costs in the area of structural restoration, says Cliff Cracauer, vice president of sales with Cortec. "In the restoration industry, there are great restrictions regarding the mechanical removal of old paint, corrosion, insulation and other barrier materials," he explains. "To address this issue, we developed a novel corrosion conversion coating that eliminates the need to mechanically remove corrosion in most circumstances. This is subsequently combined with a water-based coating system that can increase the life of a structure substantially."

Cortec's VpCI CorrVerter Rust Primer is a water-based primer for application to rusty or poorly prepared steel surfaces where further corrosion protection is required and good surface preparation is difficult to achieve. The primer is formulated to penetrate rust, eliminate rust, penetrate to bare metal and stop further rusting.

The chemical chelating agent modifies the surface rust into a hydrophobic passive layer. VpCI CorrVerter combines the chelating agent with a high-solids waterborne latex with low water-vapor permeability. The combination of the active chelating agent with a film-forming latex, thickeners and dispersant offers a unique formulation for a primer with protection against re-rusting.

"This product eliminates the need to mechanically treat a metal surface using sand blasting or dry ice blasting, which meets the market needs to reduce labor while substantially increasing the life of a structure," says Cracauer.

"As we come up with these new environmental and labor requirements, as well as new applications and capabilities that allow us to build higher, dig deeper or run hotter, we have to realize that it's not the ability to engineer the pipe or the skyscraper that allows these projects, it's the coating that protects the pipe or the skyscraper that is truly the enabling technology," notes Dow Corning's Witucki. ■

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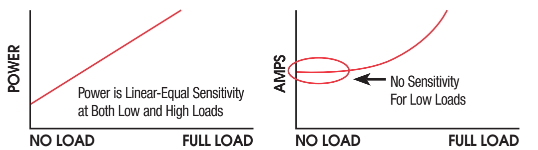

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Analyze H_2S content in liquids with this benchtop device

The Model 205L (photo) is a benchtop analyzer used to quantify hydrogen sulfide (H_2S) in liquids, including crude oil, fuel oil, naphtha, water, marine diesel, gasoline and other liquids. Specific to H_2S, the 205L has no issues with interference from other analytes. The device's detection technology is based on chemically specific density changes. Typical analysis time is 15–25 min, with only one push-button required for operation. No field calibrations are required. The analyzer provides quantitative results in parts-per-million (ppm) and parts-per-billion (ppb), up to saturation levels. Featuring an exclusive Sample Transfer Stripper filter, any mists or liquid carryovers are blocked during analysis with the 205L, reducing required maintenance time. — *Analytical Systems International Keco, Houston*
www.liquidgasanalyzers.com

Detect even small gas leaks with this ultrasonic detector

The Gassonic Observer-i ultrasonic gas-leak detector (photo) is designed with artificial neural network (ANN) intelligence, allowing it to fully analyze the sound spectrum down to 12 kHz, while distinguishing between unwanted acoustic background noise and actual hazardous gas leaks. The detector's broad leak-detection range increases sensitivity to smaller gas leaks without interference or false alarms. Providing a detection distance of up to 28 m, the Observer-i provides ample coverage in both low- and high-noise areas. Because it is adaptive, the detector requires no alarm setpoints to be configured or adjusted. A self-test function checks the integrity of the electrical components and microphone every 15 min to ensure proper continuous operations. — *General Monitors, Lake Forest, Calif.*
www.generalmonitors.com

GOW-MAC Instrument


A hydrocarbon analyzer with CO- and CO_2- detection options

The Series 2300 Total Hydrocarbon Analyzer (photo) is a microprocessor-controlled instrument designed to continuously measure the concentration of hydrocarbons in gas. By utilizing an optional catalytic methanizer with the Series 2300, carbon monoxide (CO) and carbon dioxide (CO_2) can also be analyzed. The Series 2300 employs a flame-ionization detector, where ionized carbon atoms are produced when burned in a hydrogen flame. The ionized atoms are detected and displayed as a concentration in ppm or ppb. With a high-resolution graphical touchscreen, the instrument features auto-ranging from 0 to 20,000 ppm, as well as auto-zero and auto-calibration functions. With programmable relays for concentration alarms, events and diagnostics, as well as a full array of optional output capabilities, the instrument provides longterm stability and performance in many applications, including: gas-purity certification; inert-gas contaminant analysis; carbon-bed breakthrough detection; and ambient-air and emissions monitoring. — *GOW-MAC Instrument Co., Lehigh Valley, Pa.*
www.gow-mac.com


Mettler Toledo

Wide-range-capable thermomechanical analyzers

The TMA/SDTA 1 thermomechanical analyzer (photo) is available in four versions to accommodate different furnace sizes and a wide temperature range. The instrument is optimized for measurements from –150 to 1,600°C. Both small and large samples (up to 20 mm) can be analyzed with 0.5-nm resolution without the need for range switching. A touch-sensitive color terminal for the TMA/SDTA 1 model presents clear and precise information that can be seen easily, even from a distance. All force and length calibration routines are controlled via the terminal, and the touchscreen can be used to control the determination of sample length and also to initiate the transfer of data to the software, eliminating possible transcription errors. The instrument employs a patented calculation model to determine the difference between the measured sample temperature and a reference temperature. — *Mettler Toledo AG, Greifensee, Switzerland*
www.mt.com

This flashpoint analyzer has enhanced user-interface options

The Herzog OptiFlash Pensky-Martens instrument (photo, p. 29) is capable of detecting flashpoints up to 400°C. The OptiFlash complies with global safety standards, and features an enhanced user interface and built-in automation, simplifying setup — users can now start a test without taking time for manual tasks, such as installing flashpoint and temperature sensors. The instrument is also designed for simplified cleaning and disassembly, making it more convenient to analyze highly viscous samples. The

Note: For more information, circle the 3-digit number on p. 60, or use the website designation.

instrument is also outfitted with a fast optical-flame detector, allowing it to detect a fire or small flames in an extended range around the test area. — *The Petroleum Analyzer Co. (PAC), L.P., Houston*
www.paclp.com

Inline concentration analysis for beverage ingredients production
The LiquiSonic line of analyzers (photo) provide continuous, high-precision concentration measurements in realtime. Featuring measurement accuracy of ±0.05%, the analyzer uses sonic velocity as the physical value to quickly determine concentration. If results are outside of the defined production range, a signal will be initiated to counter irregularities. Intended for use in the beverage industry, these instruments ensure high quality and process reliability by decreasing costs and risks associated with failed batches. This inline analyzer also enables efficient control of raw-material and energy consumption. For automated control, the measuring results can be transferred to the control system via analog or digital outputs. A LiquiSonic analyzer consists of one or more sensors and one controller. The sensors meet the stringent hygienic requirements of the beverage and food industries and can be integrated into any plant system. — *SensoTech GmbH, Magdeburg-Barleben, Germany*
www.sensotech.com

A trace moisture analyzer tailored for specialty gases
The DF-745 SGMax (photo) is a trace moisture analyzer optimized for measuring moisture in specialty gas streams. This analyzer delivers accurate moisture-level readings with drift-free, low-maintenance operation. Engineered to deliver an ultra-low detection limit of 5 ppb, this analyzer does not require a pump, even when such high purity is required. The SGMax features an application software specifically designed for blending specialty gases with single components and mixtures with up to eight components. The expanded database

PAC


Servomex Group

of 17 standard background gases now includes CF_4, C_2F_6, C_3F_8 and NF_3. Furthermore, users can predefine gas-mixture templates for routine blends of up to eight components. — *Servomex Group Ltd., Crowborough, U.K.*
www.servomex.com

This free-chlorine analyzer has many built-in functions
The FC80 (photo) is a panel-mounted analyzer that monitors free chlorine in many types of water-related applications, including drinking water, cooling water, rinse water or other freshwater. The standard measurement range for this device is 0.05–20 ppm chlorine, and a low-range sensor is available for measurement down to 0.01 ppm. The advanced panel-mount design incorporates a pH sensor and a chlorine sensor, as well as a built-in flow-control device, eliminating the need for pressure regulators and rotometers. Additionally, no reagents or sample-conditioning systems are required, due to the built-in pH-compensation functionality, which provides accurate compensation for samples with pH values between 6 and 9. The FC80 displays parameters graphically on user-defined line, bar or gage-style graphs. An auto-clean option includes a solenoid-actuated spray cleaner using either water or air. — *Electro-Chemical Devices, Inc., Irvine, Calif.*
www.ecdi.com


SensoTech


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High-speed spectrophotometers with immediate-start capability
The new V-700 Series of ultraviolet-visible near-infrared (NIR) spectrophotometers consists of five distinct models, each with a rugged, compact design and high-speed scanning capabilities. Two graphical user interfaces are available, including the Spectra Manager II cross-platform spectroscopy software, which allows full-system control and advanced data processing. Also standard for V-700 instruments are functions for automatic accessory recognition and immediate-start capabilities for making routine measurements. Application-specific software and accessories are available across the entire range of V-700 Series devices. — *Jasco, Inc., Easton, Md.*
www.jascoinc.com ■

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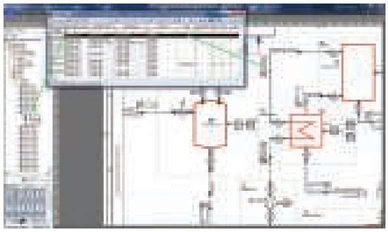


Bartec Pixavi

High-end Android smartphone for hazardous areas

Impact X (photo) is the first intrinsically safe smartphone with the same usability, performance and functionality as high-end consumer devices. The product is ready to use right out of the box, just like a regular smartphone. In addition to being Zone 1 and 2 ATEX and IECEx certified, Impact X is waterproof and extremely rugged. It has a sunlight-readable display with a touch sensor designed for heavy rain and for operation with gloves. The device has three high-end cameras, a fast processor and double the battery capacity of a typical consumer smartphone. — *Bartec Pixavi AS, Stavanger, Norway*
www.bartec-pixavi.com

Intelligent structuring and segmentation of piping

This company has developed a new function for its process engineering-oriented software system Engineering Base (EB) Instrumentation, which now makes the piping that is defined in P&ID (piping and instrumentation diagram) a lot "smarter." The new version EB 6.5.0 (photo) allows information on the flow direction, media, temperatures and pressures to be added to the P&ID. The automated target tracking shows both the beginning and the end of the piping, as well as the topology of all sub-segments with all connected components, such as valves, pumps, flaps or flanges. — *Aucotec AG, Hannover, Germany*
www.aucotec.com

Slash costs with this low-profile belt press

This new belt press (photo) for dewatering in municipal and industrial applications is based on a new low-profile design and flexible modular construction. The size and weight of the press is about half that of the previous machine generation, which means lower investment costs for the same performance. Another advantage is easier access to the machine. With an overall height of only 150 cm, the gravity zone is at the ideal working height, resulting in reduced time and costs for operating and maintenance work, as well as increasing the availability of the machine. — *The Andritz Group, Graz, Austria*
www.andritz.com

NanoSampler enables high-throughput sample delivery

The new Zetasizer NanoSampler (photo) is a versatile, compact, fully automated sample delivery system for this company's Zetasizer Nano, which is used for nanoparticle and colloid characterization. Delivering precise and reproducible automated sample loading, and accommodating up to 96 sample vials, the NanoSampler enables unattended operation of the Zetasizer Nano, to maximize analytical productivity. The new NanoSampler will work with all of the sizing systems in the Zetasizer Nano instrument range, which includes systems that measure particle and molecular size using dynamic light scattering, covering a size range from less than one nanometer up to several microns. — *Malvern Instruments Inc., Westborough, Mass.*
www.malvern.com

The Andritz Group

Malvern Instruments

UWT

Measure interfaces with this electromechanical system

The Nivobob NB3300 (rope version) and NB3400 (tape version) level-measuring devices (photo) are specially modified for interface measurement. They are designed for continuous measurement of salt or mud levels of contaminated water in tanks or silos. All installed parts have been additionally coated and prepared with robust corrosion-

Note: For more information, circle the 3-digit number on p. 60, or use the website designation.

resistant materials. The aluminum IP66 housing and process connection are unaffected by aggressive and wet media. The devices have been used in sewage-sludge and aggressive-saltwater applications. The lot systems offer a 4–20-mA signal and also communication via Modbus or Profibus DP. — *UWT GmbH, Betzigau, Germany*
www.uwt.de

Hosokawa Alpine

Size reduction for small batches — with containment

This company has extended its pico*line* series with the launch of the pico*cont* (photo), for small-batch size reduction with containment. In the pico*cont* system, the established pico*line* platform was replaced by an isolator housing made from stainless steel. The new approach adheres to the principle of strict separation of process and technical components. Now located below the unit, the technical components are not integrated into the platform, but separated from the process chamber in the isolator, and therefore protected from contamination. — *Hosokawa Alpine AG, Augsburg, Germany*
www.hosokawa-alpine.com

Vega Grieshaber

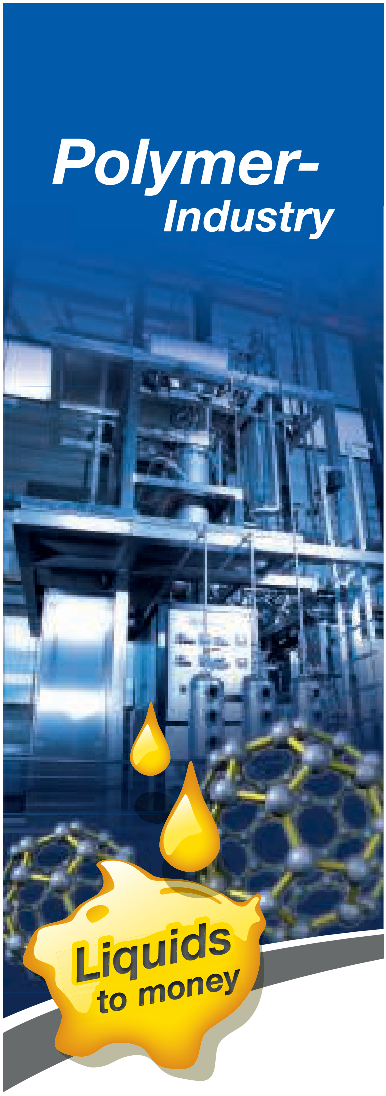
A new radar sensor for bulk-solids level measurement

The new Vegapuls 69 is available in two versions (photo) — with simple and light plastic antenna of polypropylene (PP) and with a lens antenna integrated in a flange. The level-measuring instrument operates with a frequency of 79 GHz, which enables a much better focusing of the transmission signal. This is especially important in vessels and silos with many internal components. Products with poor reflection properties that were previously difficult to measure, such as plastic powders or wood chips, can now be measured reliably. With a measuring range up to 120 m and an accuracy of ±5 mm, the device has enough power reserves even for unusual assignments, such as in mine shafts or for distance measurement in conveyor systems. — *Vega Grieshaber KG, Schiltach, Germany*
www.vega.com

Lödige Maschinenbau

Quickly blend materials with this efficient batch mixer

Designed for the preparation of bulk material, the Ploughshare batch mixer FKM 2000 (photo) features a low-maintenance mixer that delivers short mixing times, good mixing quality and high batch reproducibility. Even pumpable materials can be processed using this versatile machine. The batch mixer operates by mechanically generating a turbulent fluidized bed. In the horizontal, cylindrical drum of the FKM 2000, Ploughshare shovels arranged on a shaft rotate as the mixing elements. In this manner, the powdery, granular or fibrous bulk materials are subjected to a three-dimensional movement and the entire product is continuously



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mixed. The machines are available in various sizes with a drum capacity from 130 to 30,000 L. — *Gebr. Lödige Maschinenbau GmbH, Paderborn, Germany*
www.loedige.de

This valve series has been expanded

Now available in ½- to 36-in. sizes, the Pacific Wedgeplug valves range has been expanded to increase the breadth of solutions for users in the petroleum refining, petrochemical and power generation industries. The valve's unique design offers users a number of benefits, including increased return-on-investment: when not actuating, Pacific Wedgeplug consumes no steam, resulting in low steam usage and operational savings. The valves are designed to ASME B16.34, API Standard 599 and API Standard 600, where applicable. Testing is to API Standard 598. Special hydrostatic testing and non-destructive examinations are available. — *Crane ChemPharma & Energy, Long Beach, Calif.*
www.cranecpe.com


Phoenix Contact

Serial device servers for extreme applications

This company has extended its FL COM-Server serial device server product range (photo) with two special versions with an extended temperature and supply voltage range. COM servers enable devices with serial interfaces to be smoothly integrated into Ethernet networks. The two new models are suitable for temperature ranges from –40 to 70°C and offer a supply voltage range from 12 to 30 V (a.c. or d.c.) The devices enable easy configuration via Web-based management. — *Phoenix Contact GmbH & Co. KG, Blomberg, Germany*
www.phoenixcontact.com

An enhanced application for virtulization environments

With the release of DeltaV Virtual Studio v2.3, this company expands the virtualization capabilities in its DeltaV distributed control system (DCS) for easy implementation and management of on-line production and off-line development, test and training systems. While many large manufacturing companies have used virtualization for years in their IT departments, DeltaV Virtual Studio is designed specifically for process control systems, with a workflow and feature set that is intuitive and familiar to automation engineers. The latest DeltaV Virtual Studio release includes enhanced high availability and disaster recovery options. — *Emerson Process Management, Austin, Tex.*
www.emersonprocess.com

An infrared pyrometer with thermal imaging capabilities

The ISR 6-TI Advanced pyrometer uses a built-in video camera with infrared (IR) filter to improve manufacturing processes in metals, glass and other heat-dependent manufacturing industries. The ISR 6-TI Advanced is said to be a true breakthrough by combining pyrometry with IR-imaging technology to produce "relative" thermal images. Relative thermal images are produced by measuring the temperature of the center spot with a ratio pyrometer and using an IR filter to show an auto-calibrated thermal image based on the highly accurate ratio pyrometer temperature reading. The system provides accurate and reliable temperature measurements between 700 and 1,800°C. The analog video output signal is converted to USB and fed to a PC using the company's InfraWin software, which generates and shows a "relative" thermal image from this signal. — *LumaSense Technologies, Inc., Santa Clara, Calif.*
www.lumasenseinc.com

A patented seal for food-grade piping connections

The blue U-shaped seal is a new development that expands the range of ring seals for pull-ring connections. Blue is the recognized color for hy-

giene, and the seal conforms with both the European EC 1935/2004 and U.S. Food and Drug Admin. (FDA) standards. A special feature is that the blue ring can be detected by, for example, the company's two-way valve with a metal detector. This feature prevents parts of the ring from getting into the production process due, for instance, to faulty installation. The detectable blue U-shaped seal is a patented innovation that is exclusively offered by this company. — *Fr. Jacob Söhne GmbH & Co. KG, Porta Westfalica, Germany*
www.jacob-rohre.de

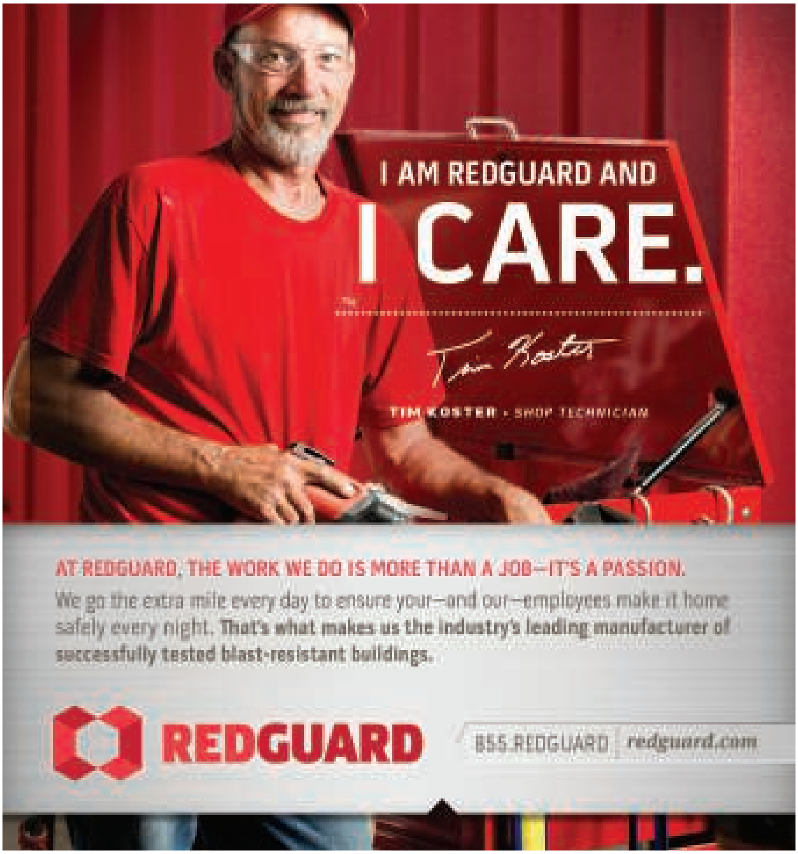
This viscometer has several new features
The new DV1 Viscometer is this company's lowest-cost, continuous-sensing digital viscometer in its family of instruments. The head of the DV1 Viscometer features a new shape and a larger easy-to-read display. Multiple language choices are now included and the user interface has three hot keys for quick access to spindle selection, test speed and other functions. Optional Wingather SQ Software allows the user to collect, analyze and record test data. Multiple tests can be compared graphically and the user can export data files to Excel. The new DV1 Viscometer includes a USB output connection for a Dymo Printer. — *Brookfield Engineering, Middleboro, Mass.*
www.brookfieldengineering.com

These actuators now support HART communication
A HART (Highway Addressable Remote Transducer) interface option is now available for this company's AC .2 and ACExC .2 controls. The adoption of the HART protocol is said to strengthen the company's position as a provider of a comprehensive range of leading-edge actuation solutions, with supporting technologies. In compliance with the IEC 61158 standard, the HART communication protocol retains the simple and classic 4–20-mA standard signal for analog data transmission, while allowing for digital communication modulated as an additional signal to the analog signal. Electronic Device Descriptions (EDD) for AC. 2 controls with HART interface will be available shortly. — *AUMA Riester GmbH & Co. KG, Müllheim / Baden, Germany*
www.auma.com

A laboratory vacuum-processing unit for small batches
The Frymix II Lab vacuum-processing unit is suitable for developing new formulations and producing very small batch sizes. The laboratory version has a usable volume of 4–12 L. The machine complies with all cGMP (current good manufacturing practices) and GAMP (good automated manufacturing practice) specifications for sterile suspensions and emulsions. The products are processed according to the rotor-rotor principle by a powerful homogenizer that was developed for temperature- and shear-sensitive formulations. The incremental adjustment of the conical milling gap and the infinitely variable adjustment of the rotor speed enable this input to be precisely defined. — *FrymaKoruma, Romaco Group, Karlsruhe, Germany*
www.romaco.com

A new vortex flowmeter for advanced energy measurement
Optiswirl 4200 is a new vortex flowmeter for the measurement of conducting and non-conducting liquids, gases and steam. The new device is targeted at auxiliary and supply applications in various industries, such as internal monitoring of energy flows for saturated and superheated steam or hot water, and heat metering applications. Areas of usage also include steam-boiler monitoring, burner-consumption measurement or compressed-air-network monitoring. In addition to gross heat calculation for steam, the Optiswirl 4200 now includes net heat calculation for steam and condensate (hot water) as well. — *Krohne Messtechnik GmbH, Duisburg*
www.krohne.com ■

Gerald Ondrey



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CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Distillation Column Modeling

Process simulation methods are used to evaluate the performance of proposed distillation systems and improve the performance of existing ones. The most common approaches for modeling distillation processes can be broadly divided into equilibrium and non-equilibrium methods. This article provides information about the differences between the two approaches and outlines their advantages and disadvantages. Due to the limitations in the assumptions used to derive each model and in the data required to accurately perform the calculations, neither model can be assumed to work best in all situations.

Equilibrium models

The longest-used (over a century) method for modeling a full distillation column is the equilibrium method, where the vapor and liquid phases are assumed to be in a state of thermodynamic equilibrium. Models based on ideal equilibrium stages are widely used to help determine the configuration of proposed columns. The approach is to divide the column into discrete stages and use computer programs to solve so-called MESH equations. The acronym MESH stands for material balances, equilibrium relationships, summation equations and heat (enthalpy) balances (Table 1). Since the 1950s, many algorithms have been developed to solve the MESH equations.

The equilibrium-stage approach offers a practical and efficient method for simulating an existing column for which data exist. The main disadvantage of the equilibrium-stage is that ideal stages are used to model real trays and packing depths. Determining what packing height corresponds to an equilibrium stage, for example, is not necessarily simple and straightforward.

Engineers have been aware for decades that vapor and liquid streams leaving a real column tray or section of column packing are rarely, if ever, in equilibrium with each other. The actual separation achieved depends on the rates of mass transfer from the vapor to the liquid phases, and these rates depend on the extent to which vapor and liquid streams are not in equilibrium with each other.

TABLE 1. EQUATIONS USED FOR DISTILLATION MODELING

Equilibrium models	Non-equilibrium models
Mass balances	Phase mass balances
Energy balances	Phase energy balances
Equilibrium equations	Equilibrium equations
Summation equations:	Summation equations
	Mass-transfer in vapor phase
	Mass transfer in liquid phase
	Energy transfer

TABLE 2. PHYSICAL PROPERTY REQUIREMENTS FOR DISTILLATION MODELING

Equilibrium models	Non-equilibrium models
Activity coefficients	Activity coefficients
Vapor pressures	Vapor pressures
Fugacity coefficients	Fugacity coefficients
Densities	Densities
Enthalpies	Enthalpies
	Diffusivities
	Viscosities
	Surface tensions
	Thermal conductivities
	Mass-transfer coefficients
	Heat-transfer coefficients
	Interfacial areas

Efficiencies

To get around the fact that real columns are not in equilibrium, modeling engineers have used various efficiencies for equilibrium-stage modeling. Murphree tray efficiencies and Hausen efficiencies are examples. Understanding efficiencies is important in the design and performance evaluation of distillation columns. Many approaches to estimating overall column efficiencies are also available. Efficiencies are often used in equilibrium-stage models to fit actual column operating data, and are said to represent the extent to which the real column departs from equilibrium. There are several limitations to using efficiencies in computer simulations, but most important is that they are a function of column conditions, and can vary from substance to substance and from stage to stage. Therefore, extrapolating to other conditions is difficult.

Non-equilibrium models

Predictions of non-equilibrium and equilibrium models often differ considerably. Although equilibrium-stage models can be useful as engineers determine initial column configurations, non-equilibrium (rate-based) models are said to offer a more realistic modeling approach. Non-equilibrium simulation methods can provide a more accurate way of checking final column designs and simulating existing columns to seek optimal separation performance.

Non-equilibrium models forego the use of efficiencies and strive to calculate the actual rates of interphase mass and heat transfer in the column. Modeling distillation as rate-based processes requires the modeling of interfacial mass and energy transfer in tray and packed columns, which is something that is not done in conventional equilibrium stage models.

Rate-based models are fundamentally more rigorous, but they require that more parameters be known or estimated (Table 2). Also, they generally require more computing power to run the algorithms.

In the past, non-equilibrium models were sometimes considered impractical due to their complexity, but ever-growing computer power has greatly increased their feasibility. Building blocks of the non-equilibrium models are the MERSHQ equations (material balances, energy balances, mass- and heat-transfer rates, summation equations, hydraulic equations for pressure drop, equilibrium equations). In a non-equilibrium model, separate balance equations are written for each distinct phase.

Numerical solutions of non-equilibrium model equations provide engineers with all of the quantitites normally associated with the conventional equilibrium model (temperatures, flowrates, mole fractions, and so on), but non-equilibrium-model calculations also provide a great deal of additional information, such as physical and transport property profiles, and equipment design and operating data. ■

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Editor's note: Tables 1 and 2 are adapted from graphics in Ref. 4.

Technology Profile

n-Butanol from Lignocellulosic Feedstock

The alcohol *n*-butanol is applied in the production of butyl acrylates to supply the coatings and adhesives industries. It is also used in plasticizers or directly as a solvent. It is commercially produced from propylene and synthesis gas (syngas) by chemical synthesis.

Due to the increasing interest in biofuels development, the production of *n*-butanol through a fermentation process is being revisited and improved. Biobutanol is an attractive renewable fuel that can be produced from the fermentation of sugars derived from agricultural feedstock — for example, corn and sugarcane — or from waste lignocellulosic materials, such as corn stover and sugarcane bagasse.

In this field, bio-butanol is viewed as an alternative to ethanol, since it fits the existing fuel infrastructure better and exhibits higher energy content, which makes it a more suitable gasoline blending fuel.

The process

The production process for *n*-butanol from corn stover via acetone-butanol-ethanol (ABE) fermentation is depicted in Figure 1. The feed handling, pretreatment and fermentation steps were compiled from a technical report published by the National Renewable Energy Laboratory (Golden, Colo.; www.nrel.gov; NREL/TP-5100-47764, May 2011) and adapted for *n*-butanol production. The purification step was based on typical ABE fermentation processes.

Feed handling. Corn-stover supply trucks send the biomass to weighting and unloading stations, followed by a short-term queuing storage and conveyors for feeding the feedstock to the pretreatment area.

Pretreatment. The biomass, composed of cellulose, hemicellulose and lignin, is treated with dilute sulfuric acid and heated in a screw-feed reactor to convert most of the hemicellulose into fermentable sugar, such as xylose. After pretreatment, the solution is flash-cooled, and water is removed, condensed and sent to the wastewater-treatment area. The mixture is then diluted with water and its pH adjusted by adding ammonia.

Hydrolysis and fermentation. In this step, cellulose is converted to fermentable glucose using enzymes. The hydrolysis is initiated in a continuous reactor and completed in several parallel batch fermenters. The slurry is then cooled and inoculated with microorganisms, which convert xylose and glucose into acetone, ethanol and *n*-butanol. The fermentation beer is then sent to the beer well before being directed to the purification section.

Purification. The fermentation beer is separated into acetone, ethanol and *n*-butanol products by a series of distillation columns, a decanter and a molecular sieve unit (to purify ethanol to commercial grade). The bottoms of the beer column, containing water and lignin, is sent to a filter. The filtrate is directed to the wastewater-treatment apparatus. The residues from wastewater treatment and lignin from filtration are burned for steam and electricity generation. The distillate from the *n*-butanol column is recycled to the acetone column to improve *n*-butanol recovery.

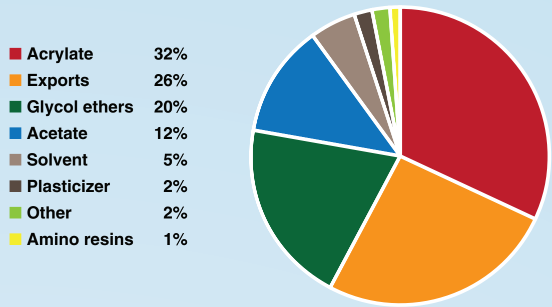

FIGURE 2. Recent U.S. *n*-butanol demand

Economic performance

An economic evaluation of the process was conducted taking into consideration a facility located on the U.S. Gulf Coast that is capable of producing 100,000 ton/yr of bio-butanol, 10,000 ton/yr of acetone and 8,000 ton/yr of ethanol.

The total estimated investment (including total fixed investment, working capital and initial expenses) for this plant is about $450 million, while the operating expenses are about $1,000/ton of *n*-butanol.

Global perspective

In the past, the ABE fermentation was used to commercially produce acetone and *n*-butanol, but this process fell out of favor because petrochemical processes became more cost-effective.

Still, the production of bio-butanol from ABE fermentation presents several challenges, such as low *n*-butanol yield, concentration and productivity, when compared to ethanol biofuel. However, recent research has been focused on enhancing such issues by developing improved microorganisms, fermentation techniques and low-energy recovery methods, in order to reduce production costs.

A good strategy to prove the bio-butanol production technology at commercial scale is to target the chemicals market, which offers higher margins and a broad range of applications (Figure 2). Later, consideration could be given to entering the fuels market, which offers far higher volumes, but lower margins. ■

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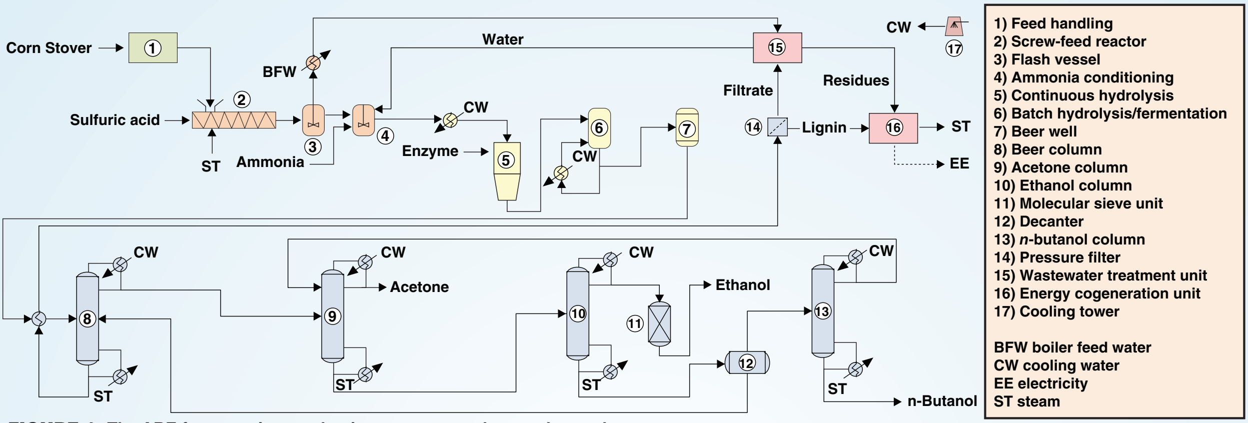

FIGURE 1. The ABE fermentation production process produces *n*-butanol

Improve Your Contingency Estimates for More Realistic Project Budgets

Reliable risk-analysis and contingency-estimation practices help to better manage costs in CPI projects of all sizes

John K. Hollmann
Validation Estimating, LLC

The average large project in the chemical process industries (CPI) overruns its sanctioned budget, including contingency, by 21%. Even more alarming, 10% of large projects overrun their budget by more than 70%. These are findings based on research by the author and others. However, research also tells us that small projects, such as those managed at the plant level or those with little individual impact on company profit, tend to underrun their sanctioned amount, often significantly. This raises many questions regarding the techniques used to improve estimates of the contingency required in these situations.

The wide accuracy range of CPI projects indicates that there is tremendous uncertainty for owner capital projects of all sizes — much more than accepted rules-of-thumb may indicate (for instance, assuming that ±10% is considered "typical"). The overruns for large projects indicate that owners do not understand the risks and are not managing them well, or are biased to underfunding the risk because proper contingency might kill the project. Conversely, small project systems understand that there is variability in project costs, but find that the most expeditious way to keep moving forward is to have a cushion in each project budget to avoid "imperial entanglements" (punitive reaction to overruns).

Because each project is unique, it is often hard for an engineer or project leader to understand appropriate costs and to see cost biases (often their own) at work. Therefore, to improve the pricing of risks in their estimates and budgets, owners must address both technical and behavioral (bias) components of risk analysis and contingency estimating. Engineers responsible for estimating budgets or managing projects must sharpen their knowledge of risk and its quantification. The first step is to fully understand the concepts of risk, contingency and accuracy as applied to cost-estimation principles.

Risk, contingency and accuracy

For projects, risk is synonymous with uncertainty. International Organization for Standardization (ISO; Geneva, Switzerland; www.iso.org), Project Management Institute (PMI; Newton Square, Pa.; www.pmi.org) and Association for the Advancement of Cost Engineering (AACE) International (Morgantown, W.Va.; www.aacei.org) standards agree that anything (threats or opportunities) that might cause project outcomes to differ from plan is considered to be a risk. Contingency and reserves are how risks are funded in project budgets. Escalation and currency exchange are additional ways, but are outside the scope of this article.

A cost estimate includes two main parts: the "base" (essentially the risk-free costs other than specific allowances) and the "risks" (contingency, reserves, escalation and currency). Separate risk types are necessary, because there are different best practices for estimating and managing them. However, engineers should keep in mind that these risk types are not always easy to parse cleanly.

Accuracy, for cost-estimation purposes, is a shorthand term to describe estimates as predictions of uncertain outcomes — the estimate is a range of possible costs, not a discrete "number." In that sense, a good estimator is one who knows, and is honest about, what he or she does not know. The person preparing the estimate must communicate the risks, the range of possible outcomes and, most importantly, how those two go together. Accuracy ranges are expressed as low and high percentages that bound the expectation of how final actual costs will differ from the estimate. For example, a range of +30%/–10% tells management that the final costs may be as much as 30% more or 10% less than the estimate after taking into account all of the identified risks. For a range statement to be complete, one must also state the confidence in this range; for in-

TABLE 1. SELECTED AACE INTERNATIONAL RISK TERMINOLOGY (DERIVED FROM RP 10S-90) [*1*]	
TERM	**DEFINITION**
Risk	An uncertain event or condition that could affect a project objective or business goal
Base (point) estimate	Estimate including allowances, but excluding escalation, currency risk, contingency and management reserves
Allowances	Resources included in (base) estimates to cover the cost of known but undefined requirements for an individual activity, work item, account or sub-account
Contingency	An amount added to allow for items, conditions or events for which the state, occurrence or effect is uncertain, and that experience shows will likely result, in aggregate, in additional costs (excludes major scope changes, catastrophic risk events and conditions, escalation and currency risk)
Management reserves	An amount added to an estimate to allow for discretionary management purposes outside of the defined scope of the project, as otherwise estimated. May include amounts that are within the defined scope, but for which management does not want to fund as contingency, or that cannot be effectively managed using contingency
Escalation	A provision in costs or prices that accounts for uncertain changes in technical, economic and market conditions over time. Inflation (or deflation) is a component of escalation
Accuracy range	An expression of an estimate's predicted closeness to final actual costs or time. Typically expressed as high or low percentages by which actual results will be over and under the estimate (base or funded), along with the confidence interval that these percentages represent

TABLE 2. AACE ESTIMATE CLASSES, DELIVERABLE STATUS AND RANGE-OF-RANGES (RP 18R-97) [*2*]			
		Range-of-ranges	
AACE Class	**Key deliverable status**	**Low end (p10)**	**High end (p90)**
Class 5	Block flow agreed upon by stakeholders	–50 to –20%	+30 to +100%
Class 4	Process flow diagrams issued for design	–30 to –15%	+20 to +50%
Class 3	Process and instrumentation diagrams issued for design	–20 to –10%	+10 to +30%
Class 2	All specifications and datasheets complete	–15 to –5%	+5 to +20%
Class 1	Most or all engineering and design work complete	–10 to –3%	+3 to +15%

stance, stating that 80% of the time, the project will be within these bounds. Also important to specify is the reference point that the range is based upon — it can be relative to the base estimate or to the funded amount, including contingency. Table 1 shows AACE International's definitions from Recommended Practice (RP) 10S-90 [*1*] of these and other key risk terms.

Understand cost risk reality

Engineers need to know that there are no "standard" estimate ranges. AACE International's RP 18R-97 (18R) [*2*] specifically states that an accuracy range must be "determined through risk analysis," because every project's risk profile is unique. RP 18R is designed to support owner phase-gate scope definition and decision-making processes by defining "classes" of estimates that align with typical industry phasing. It provides a "range-of-ranges" for estimate accuracy based on different levels of scope definition, as shown in Table 2. AACE's message regarding cost risk is that we know in relative terms that estimate accuracy will improve as scope is better defined, but in absolute terms we can't say by how much without risk analysis; risks vary too much between projects. Further, RP 18R states that its range-of-ranges excludes "extreme" risks. It also assumes that realistic, risk-based, unbiased contingency has been applied. Therefore, RP 18R's ranges bracket the estimated amount including contingency. Unfortunately, many misquote AACE as providing specific ranges. This false belief that there are standard ranges often shuts down effective communication about risks. Accuracy is not a measure of estimate quality, it is a measure of risk.

The range-of-ranges in Table 2 are classified as low-end (p10) and high-end (p90). These qualifiers are confidence levels, which are the percentage of probability (p) or confidence that the outcome will be less than the stated value.

So what are the industry accuracy ranges for owners? Figure 1 shows the distribution of accuracy outcomes for large CPI projects (typically sanctioned at somewhat better than Class 4 definition), excluding major scope change and escalation. The range is much wider, and is biased much further to the high side than the expectation of most CPI engineers. For example, the actual bandwidth is from about –10% to +70%. Comparing that width to the "worst case" in Table 2 for Class 4 of –15% to +50% highlights the discrepancies. Further, the shifted midpoint of the reality curve (median 21% overrun of budget) indicates that contingency is underestimated by a factor of about three. Here, 31% contingency was needed at p50 on average, rather than the 5–10% that industry typically allows.

Quoted ranges in literature, such as ±10% at sanction, typically reflect an estimation of process quality uncertainty, not project risks. These tight ranges reflect the estimator's and team's confidence in how well they quantified and priced the given scope. They assume nothing will change, no risk events will occur and that project control will be excellent. Of course, these assumptions are rarely realistic for owners, although they may be somewhat more realistic for contractors, for whom contingency must only cover uncertainty within the contract scope.

Figure 1 is not the only story; there also exists a stark dichotomy in industry estimation practices between small and large projects. Figure 2 depicts an example distribution of accuracy outcomes for small projects in a U.S. plant-based project system, where the project is managed by an operating facility rather than a major projects organization. At the plant level, engineers may also act as estimator and project manager. For small projects, the range is still wide; small projects do not benefit from the balancing of underruns and overruns among a multitude of cost items. However, they are biased much further to the low side. The resulting midpoint is a slight underrun. This usually reflects conservative base estimates with a generous use of "allowances."

In lean plant-based organizations, where each project leader has many projects of short duration, the emphasis is on getting operations up and running quickly and safely. One cannot spend weeks or months arguing for money to cover an overrun, so projects are frequently overestimated, often subconsciously. If excess money is returned to the business in a disciplined way, like in the example shown in Figure 2, this bias need not be wasteful, although it does lock up capital for some time. Those who understand this behavior will not be surprised that most predictable owner capital-project systems tend to be those that are most accurate. These tight-range systems tend to have an overfunding bias, and they spend the excess, which, on average can be 5–20% more than disciplined, but less predictable, systems.

To summarize the above discussion, there are no standard ranges. Large projects managed by major owner-project groups typically experience greater risk than expected and face greater cost scrutiny, so base estimates are tight and contingency is underestimated. Small projects managed by plants, while having their share of risk, are typically overestimated. So, when it comes to improving accuracy and contingency estimation, one must pay careful attention to the level of scope definition, specific risks and biases. These are discussed in the following sections.

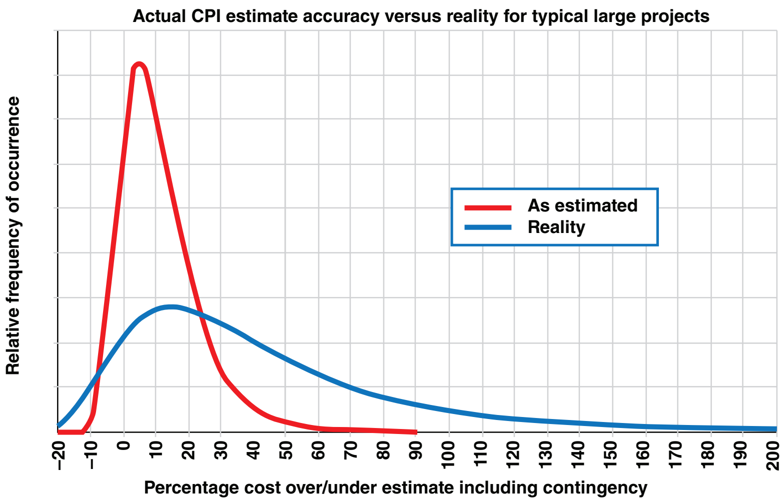

FIGURE 1. In reality, large CPI projects often miss the mark with contingency estimation methods, and large discrepancies between actual and estimated values occur

Know your scope

Table 2 illustrates how estimate accuracy improves with the level of scope definition. This is no longer an arguable topic. Since the 1990s, almost every major CPI owner company has implemented a phase-gate project system, and the phases usually line up with the AACE Estimate Classes in Table 2. The topic of scope definition, in terms of knowing which deliverables are important, and how to rate their definition, is well covered in literature. Example rating schemes for the CPI include AACE's Classes (RP 18R-97), the Construction Industry Institute's (CII; Austin, Tex.; www.construction-institute.org) Industrial Project Definition Rating Index (PDRI) and IPA, Inc.'s (Ashburn, Va.; www.ipaglobal.com) Front-End Loading Index (FEL). The level of scope definition is the greatest driver of cost uncertainty; understanding that fact is the starting point for analyzing risks.

Other key risk drivers within the project scope include the introduction of new technology in the process and the level of complexity in the physical system, as well as the execution strategy itself. Decades of empirical industry research on the impact of scope definition, technology and complexity on cost accuracy have proven these points (see sidebar on RAND and Hackney, p. 42). AACE refers to these dominant risk drivers as "systemic" risks because they are intrinsic to one's project and physical systems.

Know your base estimate

Per Table 1 definitions, the "base estimate" excludes risk — it's just the facts. Base estimating practices are well covered in literature [*3*]. Base estimating is essentially the same, whether done by an owner or contractor. Allowances for uncertainty within the base should be used sparingly. They should be limited to specific uncertain line items and well-documented markups — not general uncertainties or risk events. To avoid bias, a company should have an up-front cost strategy stating what the base estimate should represent. For example, if a company's key performance indicators call for lower absolute capital cost (rather than predictability), a policy may be as follows: "The base estimate and its assumptions will reflect aggressive, but reasonably achievable performance and pricing, excluding all contingency, escalation, currency and reserve risks."

The base estimate quality and uncertainty depend on the rigor of the project, and the estimating processes and practices that have been applied, as well as the capability and competency of the team and its tools. In addition, estimating relies on an understanding of performance on past projects, so the quality of reference data that are available, such as unit hours, is a base uncertainty driver. These base estimating factors represent "estimating-quality uncertainty," which is an important risk driver. However, one should remember that accuracy is, for the most part, not a measure of estimate base quality, but of other more dominant risks.

OPTIMISM BIAS

Perhaps the most published author on the topic of cost overruns has been Bent Flyvbjerg of Oxford University (Oxford, U.K.; www.oxford.ac.uk). His empirical research on publicly funded infrastructure projects pins the cause of major overruns on optimism bias; and, to the extent that politics and tax or rate payers are involved, on strategic misrepresentation or "lying." His articles have raised awareness of the cost situation shown in Figure 1. However, his prescription for addressing the situation, called reference-class forecasting (RCF), has been largely one of risk acceptance, where one accepts that optimism bias cannot be effectively countered, and run project economics using historical norms (the RCF) as the most likely outcome. In the CPI, we know there are effective practices, such as phase-gate systems, to improve accuracy, and that the profit motive will temper optimism bias. ❑

Biases and estimate validation

Capital project management is a realm of intense cost pressures and biases. If a high estimate scuttles project sanction, the estimator's performance rating and career development may be put at risk. In slow economic times, cancellation of a large project may mean the loss of the team's jobs. For decision makers, optimism bias often prevails. For many reasons, the desire and pressures to make a "go-ahead" project decision can be immense. The more strategic the project, the more these biases create pressure for lower cost estimates, resulting in discrepancies like those seen in Figure 1.

On the other hand, overruns may be punished, and this drives conservative estimating practices by those afflicted, particularly in small project systems (Figure 2). If the strategy is schedule-driven, as is more common in high-margin specialty chemicals or upstream production, there may also be less pressure to minimize costs, while the opposite is true for lower-margin commodity chemicals or petroleum refining.

These biases and their effect on estimating behavior are all major sources of cost uncertainty. If the bias is toward decreased base estimates (see sidebar on optimism bias), more contingency will be required, and vice-versa if the bias is toward increased base estimates (punitive cultures or small projects). In any case, one's contingency estimation methods must rate and cost these biases.

Unfortunately, bias has a political element, and is therefore very difficult to rate and price objectively. To counter this, benchmarking and quantitative estimate validation are recommended practices that measure bias relative to norms. Preferably, objective third parties will conduct these validation steps.

Estimate validation compares the metrics of an estimate to metrics based on historical data. These metrics are usually ratios of one cost-estimate element to another, such as high-level cost-to-capacity metrics, or more detailed unit hours or unit costs. For example, if the comparable historical actual data for piping installation unit hours ranges from 10 to 18 h/kg, and one has an aggressive target cost strategy, one might expect the base estimate without contingency to be about 10 h/kg, anticipating it will grow to a competitive (perhaps, aggressive but reasonably achievable) 12 h/kg upon completion. Without a cost strategy, estimators who are

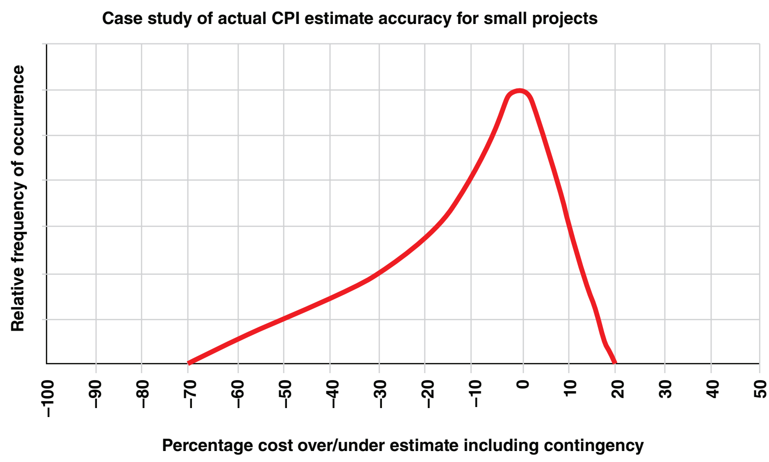

FIGURE 2. This example distribution of accuracy outcomes for small projects shows that excess capital can, in fact, be returned to the organization if disciplined planning and estimation occurs

TABLE 3. AACE RISK TYPE DEFINITIONS	
Systemic risks	Uncertainties that are an artifact of an industry, company or project system, such as culture, strategy, complexity, technology or similar over-arching characteristics
Project-specific (PS) risks	Uncertainties related to events, actions and other conditions that are specific to the scope of a project. The impacts of project-specific risks are more or less unique to that project

TABLE 4. TYPICAL MINIMUM RISK REGISTER AND INFORMATION CAPTURED

Item	Information captured
Risk title or name	What is uncertain? Be specific; avoid general issues and worries
Cause	What condition or event results in the uncertainty?
Source	Is it internal or external? Examples may be environmental, regulatory, engineering and so on
Type	For quantification, segregate systemic, project-specific and escalation risks
Probability of occurrence	Qualitative ratings (very high, high, moderate, low, very low)
Impact (in this case costs)	Qualitative ratings (very high, high, moderate, low, very low)
Risk owner	Who leads the planning for this risk?
Mitigation plan	How will this risk be addressed?
Status	How is the plan going? Is the nature of the risk changing?

left to their own devices will tend to use an approach based on "historical norms," which uses a midpoint of history or experience (14 h/kg in this particular example), which will be biased toward less competitive outcomes, because it presumes risks will happen without actually identifying or quantifying them. In any case, quantitative validation gives one an objective read of the bias, and the subsequent need for contingency.

Identify the risks

The above discussion covers the rating of what AACE calls "systemic" risks, including the level of scope definition and project system capabilities. Next, one must begin to understand risks that are project-specific (PS). Table 3 provides AACE International's definitions for these risks types; they are important to understand because the recommended methods for quantifying these risks vary by type. Note that "escalation" is a third type of risk, covering price changes driven by the economy, which should be estimated separately by methods not covered in this article.

The risk-management process starts with identifying the risks on the project. This is usually done in a workshop setting with key stakeholders and members of the project team. Risk identification can also be done via interviews or other means. Often starting with a checklist, the workshop facilitator guides the group through a brainstorming session to identify any threats or opportunities that may result in the project not meeting its objectives. These are captured on a risk register that records key risk attributes and risk-management planning elements. Table 4 shows the minimum information one will want to capture, discuss and record in a typical risk register.

Before quantifying the risks, prioritize them and focus only on those that are critical. Critical risks can create major hurdles to meeting project objectives, in this case costs. To evaluate critical risks, the team agrees to a set of qualitative ratings (very high, high, moderate, low, very low) for probability and impact with associated indicative values. For example, a "very high" rating could represent >5% of total cost and >50% probability. The team then comes to a consensus on the probability and impact ratings for each risk in the risk register. Critical risks are typically in the top category of probability and impact. If risks are well-managed during scope development, there should be very few of these. Figure 3 illustrates a typical five-by-five risk matrix, where red coloring denotes critical risks.

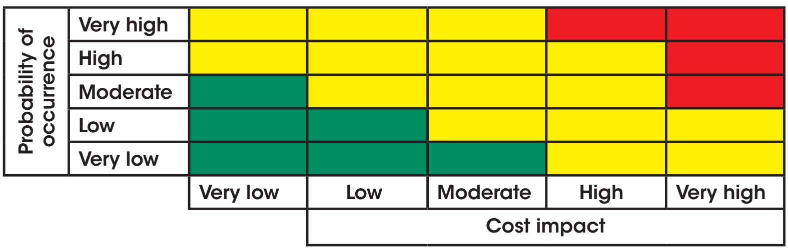

FIGURE 3. A typical probability-versus-impact risk matrix allows for quick visualization of critical risks, and facilitates simpler decision-making

Quantify the risks

Having identified the critical risks, and being at a decision point where contingency must be set, the next step is to quantify the risks. Best practice dictates the use of probabilistic risk analysis to derive a distribution of possible project cost out-

TABLE 5. TYPICAL SYSTEMIC CONTINGENCY ALLOWANCES BASED ON PROJECT ATTRIBUTES (OWNER PERSPECTIVE)										
Systemic contingency as percentage of unexpended base estimate										
Scope definition		Class 3			Class 4			Class 5		
Complexity		Low	Medium	High	Low	Medium	High	Low	Medium	High
Technology	Low	3	8	12	10	15	20	19	24	29
	Medium	6	11	15	13	18	23	22	27	32
	High	15	20	24	22	27	32	32	37	42
Adjustments to the above (select from within the ranges):										
Impurities	Feedstock or intermediate streams have solids, contaminants, corrosives, and so on: **+5 to +10**									
Bias	Aggressive base/target pricing: **+10**; Conservative base/small plant-based/punitive: **–10**									
Teams/system	Immature/weak/indecisive/understaffed: **+10**; Mature/strong/decisive/full staff: **–10**									
Fixed	Separate out costs based on firm-priced quote and use **50%** of above for that portion									
Best (p10)	After making adjustments above, the best case for sensitivities (p10) is about **–0.5×**									
Worst (p90)	After making adjustments above, the worst case for sensitivities (p90) is about **3×**									

comes. With a specific distribution and base estimate value in mind, contingency is simply the cost that must be added to get a desired probability of underrunning the total, as shown in Figure 4. Management will decide on their desired probability. Probability of underrun levels from p50 to p70 are common, depending on how risk-tolerant or risk-averse the company's management is. Note that contingency has no effect on the project's cost distribution or absolute cost range. Those are fixed attributes of the project and its uncertainty profile as it stands at that point in time. From the distribution, a worst-case value can also be obtained for sensitivity analysis (for instance, p90).

So how can engineers come up with a probabilistic cost distribution like the one shown in Figure 4? Since the 1980s, when the first Monte-Carlo simulation (MCS) add-on for spreadsheets was introduced, the traditional answer was a method called line-item ranging (LIR). This method involves assigning low and high range values (ends of triangular distributions) to one's cost-estimate line items, and running the MCS software. However, LIR has been discredited by research. It fails because it violates a first principle of risk analysis; it does not "quantify the risks." LIR does not make a risk-to-impact link. Teams cannot intuitively, and certainly not item by item, make the risk-to-impact leap. In terms of statistical significance, LIR tends to produce almost the same curve every time it is used — the red curve of Figure 1. Research published by IPA Inc. shows that LIR results in 9% contingency with ±4% standard deviation, regardless of actual risks [*4*]. The problem is not MCS itself; the problem is that the LIR model only addresses "estimating process quality" risk. However, like a broken watch, it does get the number right occasionally, such as when there are no other project risks.

Without using LIR, what is an engineer to do? Rather than fall back on a rule-of-thumb percentage, AACE recommends several risk-quantification methods that apply first principles in RP-40R-08 [*5*]. Two methods are readily available, and can be applied without specialized software and training, although, on major projects, using experts for risk analysis is highly recommended. Additionally, these two methods can provide an average contingency value without probabilistic modeling, if desired. These AACE methods are covered in the following RPs:

- 42R-08: Risk Analysis and Contingency Determination Using Parametric Estimating
- 44R-08: Risk Analysis and Contingency Determination Using Expected Value

Two methods are needed because the two very different types of risk, systemic and project-specific, must be addressed. The Parametric Estimating method is used to quantify systemic risks, because their impacts are only knowable through analysis of historical experience. The Expected Value method is used to quantify project-specific risks, because their occurrence and impacts are readily estimable by the team.

Quantification: point value only

Parametric estimating uses a predetermined equation in which the predicted average contingency percentage (to apply to the base estimate) is the equation outcome (the dependent variable), and numeric ratings of the systemic risks are the inputs (the independent variables), as shown in Equation (1).

$$MSC,\,\% = Constant + A \times (SDR) + B \times (CR) + C \times (EBR) + (OR) \qquad \textbf{(1)}$$

Equation (1) follows a typical parametric model or output of a regression analysis in the following form: *Value = constant + coefficient A × parameter A + coefficient B × parameter B*, and so on. In this case, to obtain the mean systemic-risk contingency (*MSC*) percentage value, the parameters are quantified values of scope definition rating (*SDR*), complexity rating (*CR*), estimate bias rating (*EBR*) and the product of any other coefficients and systemic risk ratings (*OR*). *A*, *B* and *C* are the respective coefficients, which along with the regression constant, are developed from regression analysis of historical data or published models in literature.

All the team has to do is rate their project's systemic risks and bias, and insert the ratings into the equation. The challenging part is developing a risk-rating scheme and an equation. Most companies do not have historical cost and risk data with which to develop an equation using regression analysis. Fortunately, rating schemes and reliable equations are available, based on 50 years of CPI research. Two time-honored rating schemes and equations are built into working Microsoft Excel tools, which are publicly available on AACE's website, and documented in RP 43R-08 (see sidebar on RAND and Hackney). For those looking for a quicker answer, Table 5 provides systemic contingency values similar to the RAND model, but instead applies a model derived by the author.

The values in Table 5 are average allowances (about p55). They assume a large gas or liquids CPI project with 20% equipment cost and typical project-management system maturity and biases. For Class 3 scope definition, it assumes that 5% of the total cost has already been spent on engineering, and that the class is over-rated. Few projects achieve ideal Class 3; most are funded closer to Class 4. As seen in Table 5, a wide range of complexity is taken into account, with low-complexity projects having less than three block-flow process steps with a simple execution strategy, and high-complexity projects having more than six continuously linked process steps or a complicated execution strategy. The technology basis varies from less than 10% of capital expenditure (capex) for a process step with commercially unproven technology to greater than 50% of capex for new, R&D or pilot scaleup steps. Engineers can make adjustments to the indicated table value as shown. The fixed-price adjustment allows for less uncertainty for that element, but there is no such thing as fixed price for owners; change and risk events will inevitably happen. Per the precedents in Table 5, an example of best/worst case (p10/p90) application is as follows: if systemic contingency is +10% (Class 4, low complexity, no new technology), the corresponding best and worst cases would be –5% (–0.5 × 10) and +30% (3 × 10), respectively. Note that the best case under-runs the base estimate in this scenario.

After quantifying the systemic risks, the Expected Value method is used for each critical project-specific (PS) risk to determine the average contingency cost to add to the base estimate. The exception is for Class 5 estimates, for which specifics are unknown and systemic contingency can be used alone. If risks have been largely mitigated during early design, and risk screening is done correctly, there will typically be less than 10 critical project-specific risks. Never quantify all of the risks in a register, of which there may be hundreds — the systemic allowance covers typical risk "noise" for non-critical risks. The simple Expected Value expression for determining the mean PS contingency value (*MPSC*) percentage is shown in Equation (2), as the summation of the products of probability of risk occurring (P_{risk}) and the cost impact (in $) if the risk occurs ($C_I$).

$$MPSC = \sum(P_{risk} \times C_I) \quad (2)$$

Consider that a workshop is held in which key team members rate the systemic risks for application of Table 5 and then discuss the critical risks and quantify their probability and most likely impacts if they occur. For example, assume the team estimates there is a 20% chance that

THE RAND AND HACKNEY PARAMETRIC COST RISK MODELS

On its website, AACE International provides two working Microsoft Excel models for quantifying systemic risks (RP 43R-08). One model is by the late John W. Hackney, a founder of AACE, as first published in his 1965 landmark text "Control and Management of Capital Projects," the 2nd edition of which is now published by AACE International. Hackney studied actual projects from his experience, and developed an elaborate contingency model based on the rating of many systemic risk factors. In 1981, the RAND Corp. (Santa Monica; Calif.; www.rand.org) published a groundbreaking report entitled "Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants" (Rand R-2569-DOE). That report includes an empirically based parametric model of cost growth, including statistical parameters. The study's lead author, Edward Merrow, went on to found IPA, Inc., and Hackney was a consultant to the 1981 study. These two publications should be on every CPI cost estimator's bookshelf. ❑

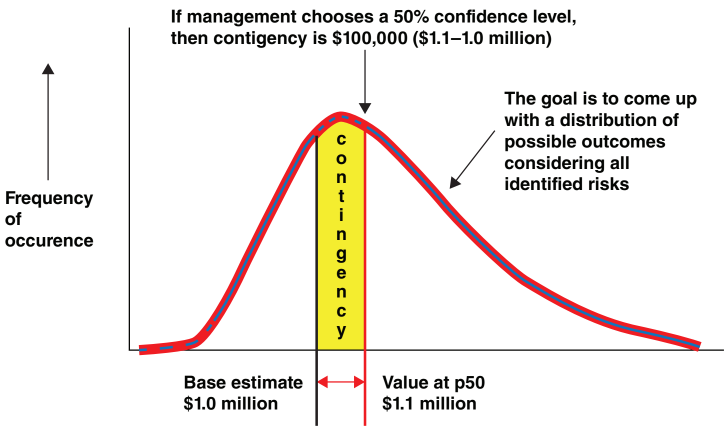

FIGURE 4. A probabilistic cost distribution can be used to determine contingency

the project will encounter rock requiring blasting in the soils during foundation excavation, and the most likely cost for this was $50,000. If the cost of rock-blasting was <1% or so of the base estimate, it probably would not constitute a "critical" risk and the team would move on to the next risk. If it was critical, say 20% probability, then the expected value to include in the contingency sum would be 0.2 × $50,000 = $10,000. Another consideration is whether this risk is a binary, discrete or overwhelming risk.

The Expected Value method works best for risks with a continuous range of impacts. In this case, the rock blasting could be $1,000 to $100,000 depending on severity. But if the impact is all-or-nothing, there is no point in putting a percentage of the impact in contingency. These types of risks should be presented to management as possible "management reserve" items that they may wish to fund in their entirety (or not) with the funds to be disbursed to the team only if the risk occurs. Using this approach, the total mean contingency is the sum of the two parts, as shown in Equation (3).

$$C_{total} = (MSC \times BE) + \sum(MPSC) \quad \textbf{(3)}$$

This equation calculates a total (mean) contingency cost (C_{total}, in $). It is the sum of *MSC* from Equation (1) times the base estimate cost (*BE*), and the summation of the mean PS contingency values for each of the PS risks from Equation (2).

For example, if the systemic contingency was 10%, the base estimate was $1,000,000, and the sum of the PS risk expected values was $50,000, the total contingency would be 0.1 × 1,000,000 + $50,000 = $150,000. Again, the corresponding worst-case value for business-case analysis would be three times this amount.

Full cost distribution

The two methods above produce a point value and worst-case for contingency. However, the best practice, as shown in Figure 4, is to develop the full cost distribution so that management can select contingency and worst-case values depending on their level of risk tolerance. This can be done using inferential statistics applied to the Parametric Estimation model, along with MCS applied to the Expected Value method, with the parametric outcome included as risk number one. For this, one must have an MCS add-on to Microsoft Excel, such as @RISK, available from Palisade Corp. (Ithaca, N.Y.; www.palisade.com), or Crystal Ball, available from Oracle Corp. (Redwood Shores, Calif.; www.oracle.com).

MCS application description is beyond the scope of this article. However, for those with knowledge of the practice, a simple MCS model can be developed by applying MCS to Equation (3). This is done by replacing the systemic contingency percentage and each PS risk-impact estimate in the worksheet with distributions per the software procedure, and simply running the simulation. The Table 5 method provides the most-likely, and p10/p90 values for systemic contingency percentage. The team, in their project-specific risk workshop, will not only estimate the most likely impacts, but the low and high range as well. The MCS software will generate a distribution similar to that in Figure 4.

Communicating the risks

Contingency is one of the most controversial topics for CPI capital-project management. Every stakeholder on the team has a different perspective as to what contingency represents, the extent to which it is necessary, and how it should be managed. This article assumes that the owner company agrees with the AACE definition; that contingency is expected to be spent. They also practice disciplined management of change on their projects. They understand that for a safe and cost-effective project, contingency under the authority of an experienced project manager is necessary to respond to risks in near realtime. Delays in response, such as requiring a committee or senior manager to review all contingency use, often result in the compounding of risk impact. The engineer must communicate this point of view to those responsible. Any distortion of these conditions will result in contingency being something other than what is described here, and its quantification tends to become more of a game.

If the company shares a common view about contingency, then communication can focus on making sure that management understands the risks' drivers and their relative impacts. Per Figure 4, contingency is selected by management decision-makers based on their risk tolerance. Ideally, risk-analysis will be done well ahead of the funding decision, so that the team has time to recycle plans to manage risks and impacts that are found to be unacceptable. The methods in this article facilitate risk communication and treatment because they are risk-driven, meaning that the risks and impacts are explicitly linked. ■

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Feature Report

Achieving Excellence in Energy Efficiency

Effective energy-management programs provide motivation for behavioral, technical and business changes that improve efficiency

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In today's environmentally conscious world, industrial energy management is increasingly recognized as an essential business practice and economic necessity, rather than an on-again, off-again activity driven by energy prices and geopolitical crises.

In this article, we examine the key elements of excellence in energy efficiency, and explore ways of pursuing energy excellence. Four main types of opportunities provide the savings: operational improvements, effective maintenance, engineered improvements and new technologies. We include experience from several companies in the chemical process industries (CPI) that have made great strides in raising efficiency and reducing energy consumption.

To support and maintain an effective energy-management system, it is important for CPI companies to establish a corporate culture that expects energy efficiency, motivates its employees, provides the organizational structure to facilitate savings, and develops the tools to achieve efficiency. *Energy efficiency only improves when both processes and human behaviors change*. Here, the "processes" include both physical plant and business processes.

Management versus efficiency

In some companies, the concept of "energy management" focuses primarily on recording and reporting energy use, and purchasing or selling energy streams. While these are important functions, they do nothing to improve the efficiency of energy utilization. Here, we use a broader definition of energy management, which includes actively working to reduce energy consumption by using energy more effectively.

"Energy efficiency" is another term with multiple meanings. The goal should not be the minimum use of energy, but the optimum use of energy — that is, the minimum use of energy, subject to a range of goals and constraints that include production requirements, environmental considerations and safety, among others.

Program components

No "silver bullet" for improving energy efficiency exists — there is no single method or approach that ensures optimal energy use in all situations. Those with a background in engineering tend to think in terms of technological options to improve energy performance — better heat recovery, more selective catalysts, higher-efficiency motors, improved process design and so on. Indeed, changing these components of physical plants can be a very powerful way of lowering energy usage. However, real-world energy efficiency is also a function of the behavior of both individuals and organizations. It follows that management and motivation are also critical factors in energy efficiency, and those factors require dramatically different types of expertise than purely technological solutions.

Comprehensive energy-management programs typically include corporate energy policies, reporting systems, benchmarking, corporate and local goals, various types of energy audits and assessments, and integration of energy-efficiency elements into engineering procedures and purchasing protocols.

Taken together, an effective energy-management program provides the motivation for the behavioral, technical and business changes necessary to improve energy efficiency.

Many resources are available to build an effective energy-management program. In the U.S., both the Dept. of Energy (www.energy.gov) [*1*] and the Environmental Protection Agency (www.epa.gov) [*2*] have been active in developing and promoting energy efficiency practices. Meanwhile, in 2011, the International Organization for Standardization (www.iso.org) launched ISO 50001:2011 to "support . . . organizations in all sectors to use energy more efficiently, through the development of an energy management system (EnMS)" [*3*].

Energy and the CPI

The CPI is one of the largest users of energy in the world, especially within its many continuous, large-scale, petroleum-refining and petrochemical-production facilities. However, the CPI also includes many smaller facilities, typically specialty plants, many of which run batch operations. There is therefore a great deal of diversity within the industry, and energy management programs must be tailored to the specific needs of individual companies and operating sites.

World-scale petroleum refineries and petrochemicals facilities have annual energy bills in the hundreds of millions or even billions of dollars, and energy used in the process is a major component of variable cost. In contrast, labor and safety and human-comfort systems, such as lighting and space heating, tend to be more dominant in many of the smaller, more specialized facilities that spend much less on energy.

Energy management is also very different for batch processes than for continuous ones. In particular, where many batch operators can apply "downtime shutdown strategies" to eliminate unneeded energy use for much of the time and thus gain "free" energy savings, this approach is not generally applicable in continuous processing.

The process sector does share some key systems and equipment. Steam systems are virtually ubiquitous, as are electric motors, heat exchangers, pumps and compressors. However, beyond these common elements there is great diversity, from distillation columns, catalytic reactors and centrifuges to kilns, crystallizers and belt dryers. Each system and each type of equipment has its own issues that must be considered within a comprehensive energy-management program.

Energy efficiency opportunities

Opportunities to improve plant performance, and thus enhance energy efficiency across the CPI, fall into four main categories: operational improvements, effective maintenance, engineered improvements, and new technologies. In each area, robust energy-management programs can support the behavioral and process changes needed to capture and maintain savings and efficiency improvements.

Operational improvements. Many operational improvements can be captured at low or no cost. Before committing to projects that require capital expenditure, it is prudent to ensure that existing equipment is being used to its full advantage — to pick up the "low-hanging fruit." This idea is illustrated in the following example: A project was planned to expand a process unit in a chemical plant. The expansion required a significant increase in cooling-water flow, and as the existing cooling-water pumps were already fully loaded, a new pump was included in the project scope. However, during a project review, the need for the new cooling-water pump was challenged, so the cooling-water system was surveyed.

FIGURE 1. Heat-exchanger cleaning programs have become an important part of energy-management systems. Shown here is hydroblasting equipment for cleaning shell-and-tube heat exchangers

Over the years, the cooling-water system had been expanded and modified several times to accommodate changes that had taken place at the site. The changes included two additional pumps and several branches in the piping, so the cooling-water system had become quite complex over time.

During the survey, it was found that cooling water was still flowing through a section of the plant that had been abandoned several years before. When the isolation valves for this section of piping were closed, the cooling-water circulation rate dropped significantly. This freed up sufficient capacity to eliminate the need for the new pump in the expansion project, which reduced the project cost by $500,000 and saved $200,000/yr in electricity costs to run the additional pump.

Operating practices tend to become ingrained over time. In the example above, no one questioned the position of the isolation valves in the unneeded cooling water circuit. More generally, operators may religiously follow procedures that were developed when the plant first started up, even though the requirements of the plant have changed over time. For example, these changes could be due to new feedstocks, different product slates, changes in throughput or a host of other factors.

Another way that operating practices can become skewed is by extending short-term responses to specific problems. For example, a cooler may be bypassed in cold weather, or a preheat exchanger may be taken out of service during a plant upset. These modified configurations can remain in place and become the new normal, and they can remain that way for years.

The immediate response when we become aware that operating conditions are suboptimal is to adjust the process (for instance, shutting the isolation valves in the cooling-water example). However, this is only a short-term fix. The next operating shift will very likely reverse the change and restore the status quo. Furthermore, plant conditions are constantly changing — the right solution today may not be the right one tomorrow or next month. We need more than just a one-time change to ensure that we get the most from our existing facilities. Additional energy-management steps might include the following:

- Modify operating-procedure documentation
- Carry out additional operator training
- Add control valves
- Implement realtime optimization systems
- Implement performance monitoring systems and key performance indicators (KPIs)

One area that often yields significant opportunities for operational improvements is the steam system — especially more complex steam systems that include steam turbines. These systems are subject to significant demand changes, and they often get out of balance. This can lead to steam venting or excessive use of steam letdowns, or both. Close monitoring, together with steam models and realtime optimization, can yield substantial improvements in energy efficiency and savings in net energy costs.

Effective maintenance. Another part of getting the most out of existing facilities is to ensure that the equipment is properly maintained. Our primary focus here is maintenance of the equipment and systems that have the largest impact on energy use — for example, heat exchangers, especially those in preheat services.

Heat-exchanger cleaning programs are an important part of many energy-management programs. This area has become quite sophisticated, with both improved cleaning techniques (Figure 1) and better tools for assessing appropriate cleaning intervals for the heat exchangers. However, the best cleaning methods and the most elegant optimization of cleaning intervals are of little use when communication fails [*4*].

During the course of a crude-unit preheat-train study in a petroleum refinery, one of the heat exchangers was found to be out of service. The records showed that this particular heat exchanger had been idle for more than three months. Further investigation revealed that the heat exchanger had been cleaned, and the work had been completed within a couple of weeks. The maintenance supervisor notified the shift supervisor that the cleaning was complete, but shift personnel were busy with other activities, and the heat exchanger could not be brought back into service before the shift ended. Unfortunately, the shift supervisor failed to advise the next shift about the situation. There was no follow-up, and the cleaned exchanger remained out of service for two and a half months.

When the unit manager was informed, the heat exchanger was brought back into service in just a few hours. The energy loss during the period that the heat exchanger had been left idle after the cleaning was worth over $100,000.

In this case, the key problem was a breakdown in communication. Better systems were needed for tracking the status of maintenance jobs on the unit. A simple electronic reminder system, for example, could have alerted the operators to the need to bring the heat exchanger back online.

In addition to heat exchangers, there are several other key systems and types of equipment that need careful attention and preventive maintenance to maintain energy-efficient operations. These include furnaces and boilers, steam traps and insulation, as well as compressors, pumps and turbines.

Engineered improvements. Additions and upgrades to plant facilities can lead to significant improvements in energy efficiency. Invariably, these upgrades require significant input from engineering personnel to identify, evaluate and design the projects. Opportunities can cover a wide range in scale and type, such as the following:

- Simple piping changes
- Localized insulation projects (Figure 2)
- Replacements of electric driver systems (such as installing variable-frequency electric drives)
- Adding heat exchangers, steam turbines, distillation columns or other major equipment items
- New control schemes

A robust energy-management system tracks opportunities, including their costs, values and timing required for implementation, so that engineered improvements can be planned, budgeted and executed.

New technologies. Engineered improvements typically use established equipment types and apply proven solutions to identified problems. In contrast, solutions that incorporate new ("breakthrough") technologies generally require some amount of validation through research and development. Thus, the amount of time required to implement new technologies is higher and their degree of technical and financial risk greater than for engineered improvements.

Some of the largest energy-efficiency improvements in the CPI have come through technological breakthroughs. For example, the development of the low-pressure polyethylene process in the 1950s was a major advance over the older high-pressure process, and the new process used much less energy per unit of production. A more familiar example for most people is the rise in recent years of compact fluorescent lights and light-emitting diodes (LEDs), which provide dramatic energy savings compared to the familiar incandescent bulbs. Technological advances have also improved some of the key equipment items that impact energy usage, such as heat exchangers and distillation columns, and incorporating some of the new types of equipment that are now commercially available can often lead to improved engineering solutions.

FIGURE 2. Localized insulation projects, such as the one shown here on the top head of a distillation column, are examples of engineered upgrades that can lead to improvements in energy efficiency

Courtesy of Aspen Aerogels

Identifying improvements

Some energy inefficiencies are endemic to the industry, and it does not require much effort to identify opportunities to improve them. This is particularly true of certain types of routine maintenance activities. For example, over time, a steam system will develop leaks and a certain percentage of its steam traps will fail, and boilers and furnaces need periodic tune-ups to remain in top condition. The question is not whether these situations create opportunities to improve energy efficiency, but rather how large the opportunities are, and what are the best ways to capture them. Many steam-trap vendors provide services to maintain steam-trap populations (Figure 3), and there are also companies that specialize in repairing steam leaks and tuning up furnaces and boilers.

FIGURE 3. Many steam-trap vendors provide services to maintain steam-trap populations within process facilities

Identifying most other types of energy-efficiency improvements requires a more concerted effort. Here are some effective approaches:

High-level site audits. High-level site audits can be used as a first step to identify where energy is used across a facility. This exercise will sometimes find specific inefficiencies, but its main purpose is to highlight and quantify major energy users, so they can be subjected to more detailed evaluation later.

Site assessments. Site assessments are typically carried out by a team of specialists that spends a period of time at a facility examining the operation of the main energy systems and major energy-consuming equipment. A typical team might include specialists in fired heaters, steam and power systems, rotating equipment, distillation operations, heat exchangers, and process design, although other specialties may participate, depending on the needs of the site. The team's role is to identify inefficiencies and define opportunities that generally include improvements in operating practices and maintenance, as well as facility upgrades.

PFD reviews. Process flow diagram (PFD) reviews [*5*] are structured brainstorming sessions designed to tease out opportunities to improve plant operations and upgrade facilities. The procedure for a PFD review is similar to that customarily used for hazard and operability (HAZOP) studies. Plant operations and technical support personnel, with assistance from energy-efficiency specialists, review each of the main streams, equipment items and systems to identify inefficiencies and areas of opportunity.

Heat-integration studies. Heat-integration studies, focusing on improving heat recovery, are also a major source of improvement opportunities on many sites. Some heat-integration opportunities are very simple and can easily be identified in a PFD review. However, some are more complex, and specialized techniques — most commonly pinch analysis [*6*] — are needed to capture them.

Steam-system modeling. Steam-system modeling and realtime optimization are also widely used to identify inefficiencies in steam systems, and to define improvements both in operating strategies and facilities (Figure 4).

Lengthy research and development programs are generally needed to create breakthrough technologies — although occasionally they appear serendipitously. Typically only companies with strong research and development programs can venture into this field, although an alert energy manager should always be on the lookout for breakthroughs that are relevant to his or her technology.

Employee suggestions yield many very attractive energy-efficiency opportunities. Employees are most familiar with the processes and practices of their site, and many of them — including some who do not have a strong technical background — have the ability to "think outside the box." These people represent a very fruitful resource, and their input into energy management should be encouraged. Some companies do this with competitions that reward the best ideas, either monetarily or in other ways. Welcoming and acting on employee suggestions is a visible and valuable way to change corporate and site culture.

Evaluating opportunities

Coming up with an idea is important, but it is only one step along the efficiency path. Opportunities must be screened to quantify their benefits and to estimate their implementation costs. They should also be tested for unintended consequences (for example, adverse effects on production) and for safety implications. First, the use of quick screening methods is effective in eliminat-

Courtesy of Soteica Visual MESA

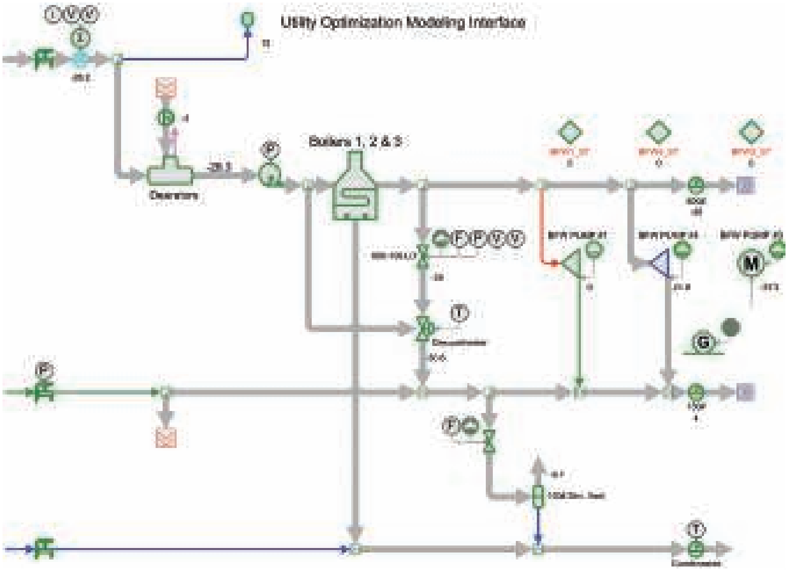

FIGURE 4. Steam-system modeling can reveal inefficiencies and help to define improvements both in facilities and operating strategies

ing ideas that are impractical or clearly uneconomic. The remaining "high-graded" ideas can then be passed on to the appropriate organization within the company (operations department, maintenance, engineering, research and development) for further evaluation and possible implementation.

Managing the energy program

Most companies within the CPI, even small companies, have at least one person with the title "energy manager." However, the roles played by these people can vary considerably from company to company. In almost all cases, the energy manager reports on energy usage and trends. This activity is often integrated into larger management systems. In some cases, the energy manager's role also includes a commercial component, with energy purchases or sales. However, if a company is committed to improving energy efficiency, it is essential that the greater part of the energy manager's job focuses on identifying and implementing energy-efficiency improvements. Remember that energy efficiency will only improve with changes in both processes and behaviors.

In order to save energy, it is important first to know where and how it is being used. It follows that an important part of the energy manager's job, especially in the early stages of an energy management program, is tracking, quantifying and benchmarking energy use. These activities highlight the most promising areas for improvement, which can then be targeted for further investigation.

Early in an energy-management program, it is a good idea to focus on simple, low-risk opportunities that can be counted on to yield energy savings with a good return on investment. Examples include steam-leak repairs, steam-trap maintenance, steam-system balancing and other easy operating changes. Successes in these areas provide credibility for the program, and the savings that they generate can provide funding for more capital-intensive projects as the program matures.

As discussed earlier in this article, energy-efficiency opportunities can be found in a great many different areas. No energy manager can expect to have the technical expertise to handle them all, so his or her role is primarily the management of resources — especially the human resources that provide the necessary skills. This requires close working relationships with the operations, maintenance, engineering and research functions within the company. It also requires reaching out to external resources where appropriate.

The energy manager should not underestimate his or her impact as a recruiter and a cheerleader. Energy managers can equip their coworkers with study results, tools and funding help, and those people can then affect energy efficiency. Real culture change arises from the people themselves. When energy managers can draw attention to good behaviors and successes, it provides reinforcement. This might be as simple as a "thank you" to a shift team that improves its energy performance. Recognition could also include a celebratory meal, a writeup in a company newsletter, publicity through an industry award, or any number of other ways of rewarding good performance.

Success stories

Many companies have reported great successes in their energy-management programs, and the energy successes are manifested in the companies' financial results. Here we summarize success stories from three very different companies within the CPI.

ExxonMobil Corp. (Irving, Tex.; www.exxonmobil.com) is one of the largest corporations in the world by any measure, with nearly 75,000 employees worldwide [7] and earnings of $45 billion in 2012 [8]. Its integrated business includes oil-and-gas exploration and production, petroleum refining, chemicals and electric power.

ExxonMobil started its Global Energy Management System (GEMS) in 2000. By 2009, the company reported that the program had identified savings opportunities of between 15% and 20% at its manufacturing sites, and had captured over 60% of these savings [9]. The company also reported significant investments in cogeneration facilities that simultaneously produce electricity and useful heat or steam. Cogeneration facilities represent a significant improvement in efficiency over traditional methods of producing steam and power separately, and they also result in lower emissions.

CCP Composites (Corbevoie, France; www.ccpcomposites.com) is a world leader in the production and distribution of gel coats, composite polyester resins, coatings, resins and emulsions, with a total of 14 plants worldwide.

CCP Composites' Houston plant participated in a pilot of the Dept. of Energy's "Superior Energy Performance (SEP)" plant certification program. SEP combines ISO-50001 compliance with an energy-management system and audited energy-efficiency improvements, and participating companies can achieve various levels of certification based on their achievements. CCP Composites achieved Gold certification in 2011, with a 14.9% improvement in energy efficiency over a two-year period. This saved 31,700 million Btu of energy, and enabled the company to capture $250,000/yr in cost savings. The savings were largely due to short-term actions and low-cost investments that have reduced natural gas demand in the process-heating and steam systems. The success at the Houston facility demonstrates that even small plants — with the appropriate corporate commitment, support and strategy — can reap significant benefits from the implementation of an energy-management system [*10*].

Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) is a global producer of specialty chemicals, including a broad range of advanced materials, additives and functional products and fibers. The company employs approximately 14,000 people around the world, and its 2013 revenues were approximately $9.4 billion [*11*].

Eastman has a long history of energy-management successes. The company ran a concerted study in the early 2000s to generate project ideas for energy efficiency, and many improvements were made — especially on the two sites that together accounted for over 90% of the company's energy use. However, in 2010, there was a major change, as the company announced an aspirational goal to inspire radical improvement and made a public pledge to the Dept. of Energy's Better Buildings, Better Plants Program [*1*] to reduce energy intensity by 25% over ten years with a baseline of 2008, the year Eastman became an Energy Star Partner [*2*]. Its current program has strong executive-level backing and a multimillion dollar budget allocated to energy efficiency projects [*12*]. The program is robust, including not only strong technical components, but also broad support and input from many internal organizations and engagement of employees at all levels. It has the following three guiding principles:

- Ensure the accuracy of utility information
- Maximize operating efficiency
- Incorporate energy efficiency in capital investment decisions

Eastman's efforts are paying off. Energy intensity improved 8% from the baseline year of 2008 through 2013. The improvement was worth $28 million in 2013 based on current production and energy prices.

Closing thoughts

Energy efficiency is an important factor in economic and environmental performance in the CPI, and many companies have made significant reductions in their energy intensity, with corresponding savings in energy costs. Four main types of opportunities provide the savings: operational improvements, effective maintenance, engineered improvements and new technologies. Many tools and techniques are available to help in identifying the opportunities at any specific facility, and a robust energy-management program supports the behavioral and process changes needed to foster efficiency improvements. Energy savings are material to company performance, and a culture of efficiency improvement can continue to pay benefits for years to come. ■

Edited by Scott Jenkins

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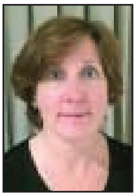


Beth Jones was, for several years, the worldwide energy manager for LyondellBasell Industries, after various positions in process engineering management and optimization in her 25 years within Lyondell Basell and its predecessor companies. She retired in 2013 to enjoy new adventures — a transfer to England with her husband and a subsequent invitation to work on a book, "Energy Management and Efficiency for the Process Industries," with Rossiter. Jones has a B.S.Ch.E. from Oklahoma State University, and is a Certified Energy Manager.

Note: "Energy Management and Efficiency for the Process Industries," by Rossiter and Jones, is currently in press and will be published by the AIChE/Wiley partnership in Spring 2015.

Solids Handling: Using Flowsheet Simulation to Improve Process Design

This tool provides advantages when it comes to modeling operations involving granular solids

Jennifer Dyment and Claus Reimers
Aspen Technology

Using flowsheet simulation to model processes involving granular solids — either those that are entirely separate from fluid processes or those that are combined with them — has many advantages for improving the process design. These include avoiding unplanned downtime, reducing costs, improving throughput and maintaining product quality.

Modeling processes that involve solids adds an extra level of complexity to process simulation, as it requires the consideration of distributed properties, such as particle-size distribution (PSD). Granular solids are described this way, whereas fluid processes are generally described using concentrated properties, such as vapor fraction, composition, temperature and so on. Additionally, many other parameters that describe the particles depend on the particle size. For instance, when particles are being dried, the moisture content inside a particle may be higher for larger particles than for smaller particles, thus moisture content is also a distributed parameter in this case.

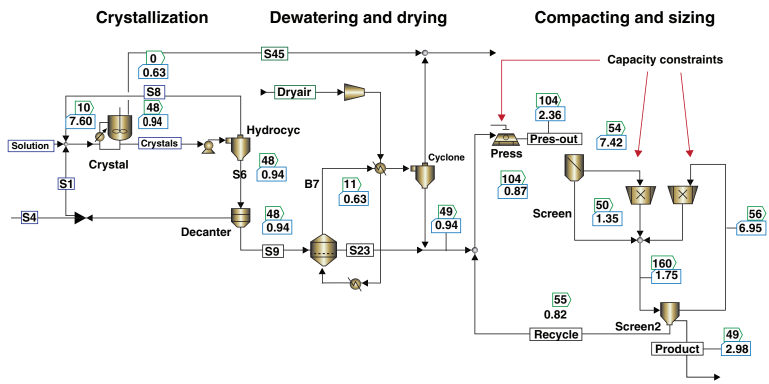
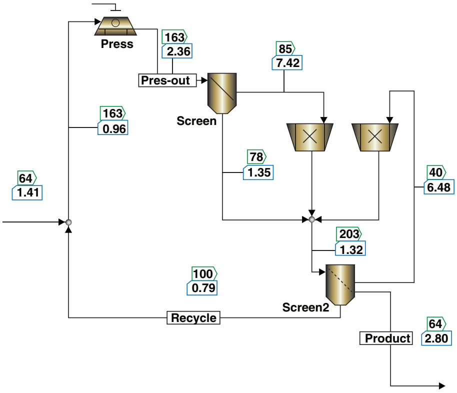


FIGURE 1. Shown here a potassium chloride process as modeled in a flowsheet simulator

In some cases, secondary distributed parameters are not important and can be averaged, but in others, they may significantly affect the process performance. As one would imagine, considering distributed parameters may increase the number of variables by an order of magnitude, if not more [*1*].

It is still common practice in industry to use averages to consider distributed parameters. An example could be the simulation of classification in a sifter. Here, the density of the particles may be assumed to be homogenous, but in some cases this might not be a good assumption and different particle types in addition to the PSD may need to be considered to describe the actual classification effect [*1*].

To address these issues, simple models may not suffice for solids-processing equipment. Instead, more advanced models that allow for multiple particle types and multiple distributed parameters may provide a more accurate depiction of what is actually happening inside a certain piece of equipment. Many process simulators offer out-of-the-box models for solids-processing equipment. These are typically programmed by experts using



Summary

	Name	Value	Units
▶	Feed Solution Flow	230	m.t./h
▶	Solid Product Flow	63.7109	m.t./h
▶	Press Inlet Flow	163.307	m.t./h
▶	Recycle Flow	99.5954	m.t./h
▶	Crusher 1 Inlet Flow	85.481	m.t./h
▶	Crusher 2 Inlet Flow	39.5665	m.t./h
▶	Impeller speed 1st mill	15	m/s
▶	OPTIM.VAR_VAL		
▶	Impeller speed 2nd mill	15	m/s
▶	OPTIM.VAR_VAL		

FIGURE 2. With an increased feed flowrate, the compacting and sizing section of the process also sees greater flowrates, and the press is now over its capacity of 144 m.t./h

industry-accepted correlations and are validated by industry peers. Compared to "homemade" models developed with spreadsheet tools or other custom modeling tools, process simulators do not require the same amount of in-house upkeep and in addition, simulation data from other parts of the process do not need to be transferred manually to the solids-process model.

Just as flowsheet simulation is crucial for designing typical chemical processes involving fluids, the larger picture in processes that involve solids is also important. This is especially important to help better understand how the solids-related sections of the process influence the fluid-related sections and vice-versa. Only a holistic model of the entire process will allow users to find an optimal design with regard to energy demand, quality and throughput.

Flowsheet simulators have been created so that users can define the PSD and other attributes, such as moisture content and density for granular solids present in a process stream, and then track changes to these attributes as a result of various solids-processing steps that are carried out. By modeling larger processes consisting of several pieces of equipment, users can track changes to the PSD within a stream as a result of changes in upstream equipment, operating conditions or material feeds. Considering the entire processes — rather than only smaller subsections — allows users to avoid suboptimal design elements resulting from localized optimization efforts. By accurately modeling changes to the PSD and other attributes, users can ensure that the product of the process is within the desired specifications, and that the pieces of equipment used within the process are adequately designed, but not overdesigned to the extent that they incur unnecessary costs.

Each process step can be represented in different levels of detail, from conceptual models to rigorous models. In earlier stages of process design, users of process simulation can use conceptual models to understand the influence of a certain piece of equipment on the entire process, before spending a great amount of effort to design it in detail.

Furthermore, some process simulators allow for additional features, such as the ability to consider the fluid and solid sections together in one simulation, as well as the costs associated with the solids-processing equipment. Combining the simulation of fluid and solid processing permits the use of the same set of property data, eliminating the need for potentially error-prone and time-consuming manual transfer of data between fluid and solids simulations. Considering costs early in design allows for better design decisions, as one could compare the relative costs associated with each variation.

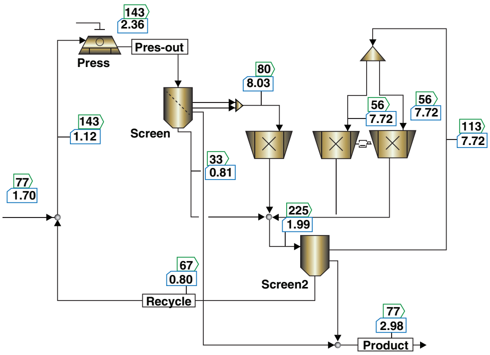
Understanding how PSD, composition, and moisture content change throughout a process, especially one with recycled streams (such as the production of potassium chloride), can help users capitalize on opportunities for increased throughput and reduced energy and capital costs.

Figure 1 shows the flowsheet of a potassium chloride production process. In the first step, a potassium chloride solution is sent to a crystallizer and the crystals that are produced are separated using a hydrocyclone. The crystals are then dewatered by a decanter centrifuge and dried in a convective dryer. Finally, the crystals enter the compacting and sizing section of the process, where the particle size is adjusted to meet product specifications.

This section of the process consists of a compacting press, screens and mills. Crystals from the upstream section of the process are combined with recycled crystals and are enlarged in the compacting press. The enlarged crystals are then sent to a screen, where the larger particles are separated, ground, and then combined with the smaller particles. Those combined particles are sent to a second screen. The particles that are too large are ground again, those that are too small are recycled back to the press, and those with the appropriate PSD exit the process as the product.

In this example, the press has a capacity of 114 metric tonnes per hour (m.t./h), the first mill has a capacity of 112 m.t./h, and the second mill has a capacity of 56 m.t./h. The right-pointing (teal) labels attached to each stream indicate the flowrate in m.t. per hour of the solids in that particular stream, while the Sauter mean diameter (SMD) of the particles in each stream is denoted with the left-pointing (blue) labels.

The base case and the entire process is shown in Figure 1. In the compacting and sizing section of the process, the press and mill ca-



Summary

	Name	Value	Units
▶	Feed Solution Flow	290	m.t./h
▶	Solid Product Flow	76.5125	m.t./h
▶	Press Inlet Flow	143.143	m.t./h
▶	Recycle Flow	79.9534	m.t./h
▶	Crusher 1 Inlet Flow	56.284	m.t./h
▶	Crusher 2 Inlet Flow	9	m/s
▶	Impeller speed 1st mill	8.88269	
▶	OPTIM.VAR_VAL	5.75	m/s
▶	Impeller speed 2nd mill	5.75	m/s
▶	OPTIM.VAR_VAL	5.73698	

FIGURE 3. With a new process configuration and optimized parameters, the process now produces 57% more potassium chloride while meeting equipment constraints and product quality requirements

pacities are not closely approached and there is an opportunity for the product flowrate to be increased. The feed solution flowrate can be increased 144% (from 160 to 230 m.t./h). The impact of this change can be seen in Figure 2, where only the compacting and sizing section is shown.

With this change, the press is now over its capacity of 144 m.t./h at 163 m.t./h due to a high recycle flowrate of fines from the second screen which is the result of over grinding by the two mills. Here, there is an opportunity to adjust the impeller speeds of the mills to minimize the recycle stream so that capacity constraints of the press are met. Instead of using trial-and-error, a flowsheet simulator and its optimization tool can be used to find the optimal impeller speeds that would be needed to minimize the recycle flowrate while meeting the capacity constraints on the three pieces of equipment.

The optimization study shows that the optimal impeller speeds are 14 and 8 m/s for the two mills, while the initial speeds were both 15 m/s. With these changes applied, the recycle rate is minimized, but it is still very large for the process. The change reduces the recycle flowrate from 100 m.t./h to 79 m.t./h and the flowrate to the press is now below the constraint. A preliminary cost estimation of the capital and utility costs of the entire process amount to \$15.5 million and \$0.39 million, respectively.

While the recycle flowrate was already minimized under the given conditions, it can be further reduced by addressing the second mill, which is at capacity. Additionally, a portion of the particles exiting the press might already be at the correct particle size and thus, a screen with three decks could separate the particles that are not too small or too large and direct them to the product stream. These changes to the structure of the process were applied and the new configuration can be seen in Figure 3.

By adding these changes, the recycle stream is reduced to 66 m.t./h, the press now has spare capacity, and the feed flowrate can be increased. By further minimizing the recycle flowrate by adjusting the impeller speeds of the three mills and increasing the potassium chloride solution flowrate, the product flowrate is maximized. With the optimized impact velocity and the alternative design it is possible to produce 57% more potassium chloride. The final process modifications can be seen in Figure 3. Using preliminary cost estimation, the different process configurations can be compared. With the adjustments made in this example the process now produces 46% more revenue while the capital costs are only 15% higher (which includes the new mill) and the utility costs are only 4% higher.

Further modification and optimization may be necessary for the rest of the process. For instance, an analysis could be done around the dewatering and drying section of the flowsheet. The energy use associated with the hydrocyclone and the decanter centrifuge, as well as the dryer, could be minimized.

Understanding how the PSD changes throughout a process — especially one involving recycle streams, such as those in the compacting and sizing section of the potassium chloride example given — can help users capitalize on opportunities to achieve increased throughput, and reduced energy and capital costs. Without flowsheet simulation and the rigorous peer-validated models available today, many potential improvements to the process may go unnoticed and the benefits of reduced costs, increased throughput and improved quality may go unseen. ■

Edited by Suzanne Shelley

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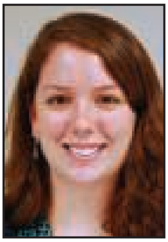

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Fire-Water Pumps for CPI Facilities

FIGURE 1 Fire-water pump assemblies are typically skid-mounted to ease installation and operation. Shown here is an example of a skid-mounted, diesel-engine-driven, fire-water pump package

Follow this guidance to improve the selection, design and operation of pumps handling water for fire-fighting and related systems

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Consultant

Fire-water pumps are critical machines that save lives and prevent chemical process industries (CPI) facilities from damage more so than any other plant components. Fire-water pumps are nearly always centrifugal pumps with capacity from around 20–3,000 m^3/h. Specific requirements for fire-water pumps are briefly noted in fire codes (such as NFPA 20 [*1*]), but this may not be sufficient for specifying high-performance fire-water pumps in a way that ensures good reliability and operation as well as optimum price. This article provides practical notes on fire-water pumps to expand upon the information that can be found in existing fire codes.

Various styles and configurations of fire-water pumps are available at different prices. In addition to proper selection, fire-water pumps must be properly integrated into the overall fire-water system, as an integral part of the CPI facility.

Figure 1 shows an example of a skid-mounted, diesel-engine-driven fire-water pump package. The performance and reliability of a fire-water pumping system is an important issue, and details of the fire-water pumping system are usually a part of risk studies, HAZOP and inspection activities.

Fire-water pumps are important to different stakeholders, including clients, investors in the CPI plant, and insurance providers. Usually around 20–35% of the insurance-deficiency rating points for a CPI plant are related to inadequate fire-water pumping systems. On average, 5–10% of all fire-water pumping systems in CPI plants have failed to provide satisfactory services at the time required (as evidenced during actual fire cases or drill-type exercises). Thus, it is critical to design, implement, operate and maintain these critical systems — beyond the minimum requirements set forth in published fire codes.

Fire-water system

Fire-protection efforts are categorized as passive or active. The primary passive measures for fire protection include efforts to ensure sufficient clearances, install protective barriers, limit and protect fuel sources, and other steps designed to reduce fire risks (such as the use of less hazardous materials, processes and equipment). By comparison, active fire-protection systems are designed to detect and apply fire-protection measures, which usually rely on some effort to actually extinguish the fire. Commonly used system components include fire hydrants, monitors, hose reels, water-spray systems, deluge-type fire-protection systems or water-exposure cooling systems. The fire-water pump plays an important role in most active fire-protection systems.

System design and sizing

There have been different sets of rules to define the required flow and head of fire-water pumps. In other words, a variety of different guidelines have been used to estimate the ideal water volume and flow requirements for CPI fire cases, depending on plant specifics, applicable codes, regulations and fire-fighting methods. As a result, these specifications will vary based on whether the plant is using fire control, fire suppression, exposure cooling and so on.

Fire-water demands are usually calculated based on the maximum rate of water that will be required for a worst-case scenario — typically a potential scenario involving a large, single-fire incident. The most remote unit(s) from the fire-water pumps, or the largest unit(s), are typically examined to identify the worse possible fire scenario(s). The potential scenario of a vast fire in the largest unit should be used to define the capacity of fire-water system. The most-remote fire unit(s) should be used to define maximum rated pressure of the fire-water pump.

CPI fire cases can be very different, considering the different types of materials handled and the types of operations carried out at different facilities. Today, computerized simulations play a critical role in identifying and modeling potential fire scenarios, validating fire-fighting methodologies, and estimating the required water capacity.

When evaluating a potential fire-fighting scenario, additional pressure (a safety margin to the calculated head) should be added to maintain the fire-water pressure in all remote units and critical fire-fighting systems; this is necessary to ensure that a fire-water stream with adequate pressure can be maintained to support all applicable fire-fighting systems should there be a fire in a unit.

Fire-water and utility-water systems have sometimes been combined in non-critical plants. In the event of a fire, the connected utility water system would be tripped. However, these combined systems are always risky. Various fire codes recommend that no utility-water connections be made to the fire-water system. In some special cases, the fire-water system may be used for emergency process-cooling requirements, but only as the secondary (reserve) supply.

Fresh (treated) water is always preferred (over seawater, brackish or untreated water, for instance) for fire-water systems in all onshore plants. Untreated or brackish water can cause many issues such as corrosion, which can potentially wreak havoc on the system components.

In general, engineers should purchase or construct the fire-water pumping system and the fire-water distribution system using proper materials (for instance, selecting suitable corrosion-resistant materials or proper protective coatings), because untreated raw water (such as seawater) could be used as the secondary source for extra fire-water capacity, in the case of an unexpected fire event. If this happens, the fire-water system should be flushed with treated water after the incident, to remove residual traces of untreated source water.

Selecting fire-water pumps

Centrifugal pumps with a relatively flat characteristic performance curve (a graph of head versus flowrate) are generally selected for fire-water pumps. Ideally, the head should rise continuously from the rated point to the shutoff point, with only a small increase of head (say, a 9–15% rise of the head from rated point to shutoff point). These pumps can provide a steady, stable flow of water at a relatively uniform pressure over a wide range of required fire-water flowrates.

A relatively flat performance curve is always encouraged for centrifugal fire pumps for the following reasons:

- The control of a fire event usually requires variable amount of water at a relatively constant pressure
- Fire-water pumps are typically operated in parallel. A relatively flat curve ensures troublefree parallel operation

Sometimes, a large amount of water can be required by the fire-water system to battle a vast fire; in those cases, the required water could be considerably larger than the rated flow of the pump. In this regard, the fire-water pump overload point (the end operating point at the right side of the pump curve) should demonstrate a capacity of more that 150% of the rated capacity at a head more than 70% of the rated point. In other words, operation point could move to the far right side of the rated point and that point should offer sufficient flow and head.

A steep pump curve should always be avoided. As a rough indication, the average slope of a fire-water pump curve should preferably be around 10–20% (for instance, an average slope of 1/10 up to 1/5).

Fire-water pumps can idle against closed valves for a short period of time. In other words, for a short time, the pump should be able to operate in a closed water system without any fire-water application.

Check valves should be provided at both the discharge and the suction. The rated pressure of a fire-water pump could be 4–30 barg. Single-impeller centrifugal pumps (for applications that require pressure below roughly 12 barg), and multi-impeller centrifugal pumps (for higher-pressure systems) are also commonly used.

The differential pressure of a pump is proportional to both the square of the rotating speed and the square of the impeller diameter. A discharge pressure of around 10 barg can be obtained by a relatively large, single-impeller pump (with a suitable speed).

Overhung (OH) pumps have been used for small- and medium-sized fire-water pumps. Users should consider the between-bearing (BB) pump design when size, power rating and power-density exceed a certain level. As a rough indication, this limit could be 400 kW.

FIGURE 2. Shown here are several examples of fire-water pumps; an identical spare pump is commonly used to increase the reliability of fire-water pumping systems

As noted, the fire-water pumps installed at any given facility should be able to operate in parallel. However, there are some challenges and issues in ensuring parallel operation. Even in certain conditions, pumps designed to operate in parallel could be subject to overheating or damage. A well-known danger is one pump operating at higher flow, forcing another pump to operate at lower flow; operation at lower flow can be damaging to the pump.

When fire-water pumps are operated in parallel, the pump with the lowest head may work at a reduced flowrate. In this way, the pump could work far from the "best efficiency point" with a very low efficiency, high friction and heat generation, which can result in damage. Even in identical fire-water pumps, pumps that have been in use for more hours (and thus has probably been subjected to more wear), pumps with minor defects, and pumps with slightly lower speed could all be subjected to a reduced flow, which can create problems during an actual fire event. Because of this effect, operators should rotate pumps over time, so that each pump works as the main fire-water pump for some period of time; this can help to ensure even wear patterns among identical pumps in service. Individual protection against the minimum flow (to ensure a minimum flow for each pump) is recommended.

Monitoring of the differential temperature of each pump can provide valuable insight for estimating the parallel operation issue (the reduced-flow problem) and resulting inefficient operation (overheat). In case of reduced flow, the differential temperature (the discharge temperature minus the suction temperature) would rise and could indicate such a malfunction.

Because of small leakage and small consumption of fire water, the pressure in a fire-water network could decrease slightly. Fire-water pump systems are usually designed in a way that spare pumps should be started if fire-water pressure dropped below a certain level. However, a slight pressure drop should not lead always to the startup of a large fire pump, as this could result in many unnecessary on-off operating cycles of the main fire water pump (Figure 2).

On the other hand, small pressure changes resulting from variations in fire-water consumption during a fire incident can result in an unstable operation of the main fire-water pump(s). For instance, this may lead to unnecessary fast changing of the operating point of a large pump, which can result in performance and reliability issues.

Smaller-capacity pumps (known as "jockey" pumps) are usually employed in conjunction with the main pump(s) to maintain a relatively constant fire-water pressure. Jockey pumps usually initiate operation after a relatively small pressure drop (say 0.5–1 bar) in a fire-water system.

Main fire-water pumps are typically electrically driven and the spare (backup or reserve) fire-water pumps are typically driven by diesel engine. A commonly used arrangement for critical CPI facilities is to install six fire-water pumps, including two electric-motor-driven pumps, two diesel-engine-driven pumps and two jockey pumps. Fire-water pumps are nearly always provided on a prefabricated skid. This packaging concept can help to ease the alignment and installation issues and ensure high reliability.

As noted earlier, the fire code NFPA 20 is dedicated to fire-water pumps. It specifies proper requirements for pump tests, pump performance curves, pump accessories and auxiliaries, and some packaging details. However, in this author's view, NFPA 20 should be considered as a minimum requirement for a fire-water pump. For critical fire pumps, the well-known API-610 pump standard [*2*] is additionally applied.

API-610 fire-water pumps

The API-610 pump standard is used to ensure the reliable operation of high-performance pumps, mainly in the oil-and-gas, petroleum refinery and petrochemical sectors. The API-610 is usually considered to be the minimum specification for pumps that handle hazardous, flammable, toxic and explosive liquids since any reliability issue associated with these pumps could result in a potential disaster. API-610 pumps are also very popular in applications with extreme temperatures, including pumps for both high-temperature service (such as boiler-feed-water, or BFW, pumps) and low-temperature applications (for example, pumps used in liquid petroleum gas (LPG) liquefied oxygen, and liquefied natural gas (LNG) service). For critical (high-risk) CPI units, fire-water pumps are usually specified to comply with the API-610, to ensure that they are able to achieve a high reliability level — the same as other pumps in the unit.

Engineers often struggle with whether or not to use API-610-compliant fire-water pumps for a CPI plant. This decision would depend on the application, pump head, power rating, capacity, pump speed and expected reliability. The main variable is CPI service (the CPI plant and expected reliability). For instance, for critical units handling flammable liquids and gases, API-610-compliant fire-water pumps are often preferred.

For a fire-water pump with differential pressure more than 20 bar, API-610 is usually specified. The pump power rating is a bit tricky, since there are many non-API fire-water pumps available (with successful references) that are intended for high power ranges in a wide array of industry applications. As a general rule of thumb for many CPI plants, API-610 can be considered for pumps above the 350-kW range.

Fire-water pump arrangement

The location for fire-water pumps should be selected carefully to minimize various risks and potential hazard situations. Explosions or high-hazard fires are major concerns, which can disable fire-water pumps. Ideally, there should be 40–80 m of clearance between fire-water pumps and a hydrocarbon or chemical process unit or storage area. This limit should also be respected for some utility areas, such as a power-generation units, gas-compression units, oxygen-generation units, and similar.

The possibility of an unconfined vapor-cloud explosion is one of the main concerns, as this could disrupt utilities, damage major support facilities, and damage the fire-water pumping system. Generally, there is a great possibility of the electrical network or the steam-distribution system failing in the event of a major explosion or extensive fire event. This underscores the critical role of independent, diesel-engine-driven fire-water pumps. Fire-water diesel engines should generally comply with NFPA 37 [*3*].

Regarding the diesel fuel-tank capacity, typically, a 12-h duration is specified as the minimum requirement. However, some critical CPI plants require 24-h-capacity fuel tanks for each fire-water pump-diesel engine.

Meanwhile, each diesel engine should be provided with independent auxiliaries and accessories, including a dedicated fuel system and fuel tank. The startup of the engine is commonly managed by a battery system (with two independent barriers).

The failure of a diesel engine is usually the result of a problem with one of the auxiliary systems. Major reasons for such a failure include fuel-system issues, a lubrication-system problem, a starting issue, a wiring problem or component fatigue. Only clean, high-quality diesel fuel should be used, and special attention is required for the lubrication oil selection and supply.

Proper overhauls and repairs

are required, just like for any other properly designed combustion engines. Experience has shown that the diesel-engine-driven, fire-water pump is the most reliable option currently available for severe loss incidents in a CPI plant. The reliability and availability of microturbines (small gas turbines in the 50–400 kW range) could be higher than diesel engines, but their efficiencies are relatively lower (in terms of lower operating duration with the same amount of fuel). Currently they are not popular for fire-water pump systems.

Fire-water pumps are typically arranged for both manual and automatic startup. Automatic startup is expected to happen rapidly, in a very reliable manner, once a fire event has been detected. Fire-water pumps are usually stopped manually at the pump's local control panel. In other words, operator intervention is usually used to turn off the pump, once the situation has stabilized and the fire is out.

A suitable enclosure (or building) should be provided for fire-water pumps. Sufficient reinforcement should be considered for the fire-pump enclosure. This is very important. For example, in the case of a major earthquake, fire-water pumping systems need to be fully operational to respond to fire events resulting from the earthquake. An open-sided shelter is not recommended. And, fire-water pumps should be located at a higher elevation than the majority of the CPI facility and upwind of it.

To provide another layer of protection (in order to avoid common failures), the main fire-water pumps, and any other reserve or supporting fire-water pumps should not be located immediately next to each other. Locating fire-water pumps at two separate locations can improve both the fire-water system reliability and overall fire-water network hydraulic behavior.

Special fire-water pumps

For critical CPI plants, additional emergency (or reserve) firewater pumps should be provided — in addition to the conventional fire-water pumps — to supply seawater (for CPI plants located at the coastal regions) or other sources of untreated raw water (such as untreated water from a lake or water wells), to quickly supply additional capacity to the plant's fire-water network.

For a seawater-based emergency fire-water pumping system, the pumps are usually submerged in seawater. For some locations, the seawater level may fluctuate from –7 m to +16 m. Considering that there is often a long distance from the sea to the CPI facility, these fire-water pumps should be designed to produce a relatively high head. These special fire-water pumps are usually multi-impeller pumps. Properly designed highly reliable pumps are always specified for such complex service. Electric-motor-driven submersible pumps, or sometimes hydraulic-driven pumps are used for these special applications. These are usually down-hole, vertical turbine-type pumps.

In some cases, local regulations or plant specifications require three dedicated fire-water pumps (as the minimum) for special CPI applications (such as CPI plants that handle highly explosive or highly flammable materials). In such cases, one of the main concerns is personnel safety during a major fire case and provisions must be made to ensure a safe personnel evacuation.

Installation and commissioning

The piping installation and connection to a fire-water pump can lead to relatively high loads on the pump nozzles and to the pump train's sensitive components, such as bearings, coupling and rotating assemblies.

The fire-water pumps are often left on standby, therefore any high nozzle loads or misalignment might be left unchecked. This can potentially wreck the pump in the first hours of operation in the event of fire. Periodic checks are important.

A well-known method to monitor the movements and deformations of critical machinery components during the piping connection (piping flange and machinery flange bolt tightening) is to install dial indicators (or other types of indicators) that monitor movements in critical parts of the machinery train. Usually, two dial indicators are used to observe movement in each machinery component (such as the driver, the fire-water pump and the gear unit, if any) compared to the baseplate or foundation (the main purpose is to identify improper support of machinery, called "soft-foot").

Two dial indicators can be used to monitor critical bearing housing movements in the fire-water pump (usually in x and y directions). Acceptable movements should be below 0.04 mm (40 micrometers) to ensure a proper piping-pump connection. A similar limit should be applied to movements in all critical pump train locations (such as bearing housing, coupling, machinery support and others), and suction and discharge nozzle flanges (in terms of limiting deformations in all directions). For special fire-water pumps, depending on the machinery design, speed, power rating and applications, a limit higher or lower than the above-mentioned (0.04 mm) may be specified. ■

Edited by Suzanne Shelley

References

1 NFPA 20, Standard for the Installation of Stationary Pumps for Fire Protection, National Fire Protection Assn. (NFPA), 2013.

2 API 610, Centrifugal Pumps, American Petroleum Inst. (API), 2009.

3 NFPA 37, Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines, National Fire Protection Assn. (NFPA), 2014.

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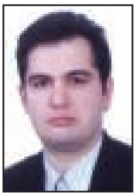

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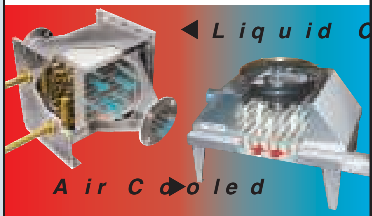

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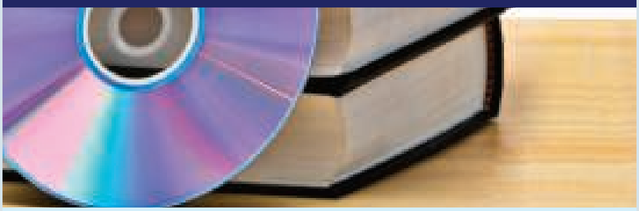

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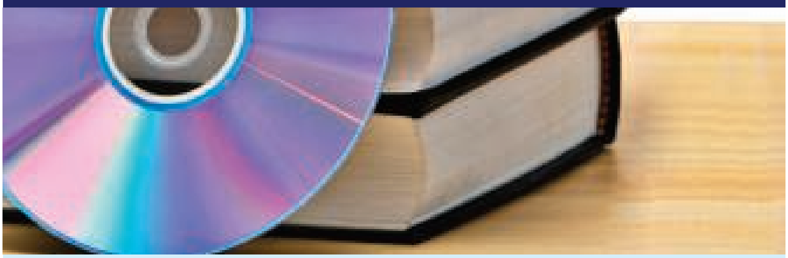

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People

WHO'S WHO


Jamani


Oxman


Fraser


Mulligan


Milano

Nova Chemicals Corp. (Calgary, Alta.) names *Naushad Jamani* senior vice president, olefins and feedstock. He replaces *Grant Thomson,* who is retiring.

Michael Oxman becomes a partner at **Acorn International** (Houston), a provider of environmental- and social-risk-management services.

Greene's Energy Group LLC (Houston), a provider of integrated testing rentals and specialty services, names *Robert Fraser* regional business development manager. Based in Dubai, he will be responsible for developing business initiatives in the Middle East, Africa, Asia-Pacific region and countries surrounding the Caspian Sea.

Demelza Mulligan becomes manager for wire-weaving and machinery maker **Haver Southern Africa** (Johannesburg, South Africa), succeeding *Joachim Hoppe*, who is returning to Germany to found Haver & Boecker's new business unit, *Bergbau*/Mining.

James Forte joins life-sciences consulting firm **Kineticos** (Raleigh-Durham, N.C.) as managing director.

Hill International (Marlton, N.J.), a provider of construction-risk-management services, promotes *John Milano* to senior vice president and Northeast regional manager for the project management group. He replaces *D. Clarke Pile*, who will continue working with Hill as an executive consultant. ■

Suzanne Shelley

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BUSINESS NEWS

PLANT WATCH

Momentive to construct two formaldehyde plants in Louisiana
November 10, 2014 — Momentive Specialty Chemicals Inc. (Columbus, Ohio; www.momentive.com) plans to build two new formaldehyde plants in Geismar and Luling, La., with operations expected to begin in early 2016 and late 2015, respectively. With an investment of approximately $66 million, the new plants will add formaldehyde capacity of more than 400,000 metric tons per year (m.t./yr).

KBR awarded FEED contract for butadiene expansion project in Saudi Arabia
November 6, 2014 — KBR Inc. (Houston; www.kbr.com) has been awarded a front-end engineering design (FEED) contract by Saudi Basic Industries Corp. (SABIC) for the debottlenecking and expansion of SABIC's Petrokemya butadiene extraction plant in Al Jubail, Saudi Arabia. The plant currently has a butadiene capacity of 123,000 m.t./yr, which will be significantly expanded with this project.

Evonik opens new plant for functionalized polybutadienes in Germany
November 3, 2014 — Evonik Industries AG (Essen, Germany; www.evonik.com) has opened a new plant for hydroxyl terminated polybutadiene (HTPB) in Marl, with a production capacity of several thousand metric tons per year. Evonik's HTPB will have the brand name Polyvest HT, and will primarily be used in sealing compounds and adhesives.

AkzoNobel begins operations at Dubai powder coatings plant
November 4, 2014 — AkzoNobel (Amsterdam, the Netherlands; www.akzonobel.com) has started operations at its new powder coatings plant in Dubai. The plant will target growing regional demand for powder coatings, particularly from the architectural sector, as well as functional products used in the oil-and-gas and construction markets.

Vencorex to expand isocyanates in the U.S., France and Thailand
October 30, 2014 — Vencorex (Saint-Priest, France; www.vencorex.com) is planning to increase its capacity for aliphatic isocyanates with several projects worldwide, including: an expansion of monomer capacity in Pont de Claix, France by 70,000 m.t./yr; a new derivative unit with 12,000 m.t./yr initial capacity in Rayong, Thailand; and investment in new U.S. production facilities for waterborne polyurethane coatings in Freeport, Tex.

DSM to build polymerization plant for polyamide 6 in Georgia
October 29, 2014 — Royal DSM (Heerlen, the Netherlands; www.dsm.com) will build a new polymerization plant in Augusta, Ga. The plant, which will become part of DSM's Engineering Plastics business group, will manufacture high-viscosity polyamide 6 polymer for film grades used in flexible food packaging and other segments. Construction of the plant is scheduled to start in early 2015, with completion targeted for mid-2016.

BASF to increase production capacity for *t*-butylamine plant in Nanjing
October 28, 2014 — BASF SE (Ludwigshafen, Germany; www.basf.com) will expand the production capacity of its existing production plant for *t*-butylamine (tBA) at the Nanjing Chemical Industry Park in China. The company plans to increase tBA production capacity by 60%, from 10,000 to 16,000 m.t./yr. The expansion is expected to come onstream in early 2015.

Westlake to expand capacity for ethane-based ethylene in Louisiana
October 24, 2014 — Westlake Chemical Corp. (Houston; www.westlake.com) will expand its ethylene capacity and make other capital improvements in Lake Charles, La. with an investment in excess of $330 million. The expansion is expected to be completed in late 2015 or early 2016, and will increase ethane-based ethylene capacity by approximately 113,000 m.t./yr.

Chemtura expanding antioxidant capacity in Italy, Canada and Taiwan
October 20, 2014 — Chemtura Corp. (Philadelphia, Pa.; www.chemtura.com) is increasing capacity at three production sites for alkylated diphenyl amine (ADPA) liquid antioxidants. In 2015, the company plans to increase capacity at its Elmira, Ont., Canada site by 20%, its Latina, Italy site by 25%, and its Kaohsiung, Taiwan site by 10%.

MERGERS AND ACQUISITIONS

Vertellus increases life-sciences presence with Pentagon acquisition
November 3, 2014 — Vertellus (Indianapolis, Ind.; www.vertellus.com), a producer of pyridine and pyridine derivative chemicals, has purchased Pentagon Chemicals Ltd., a manufacturer of fine and specialty chemicals used in the life-sciences industry. The transaction is expected to boost the earnings of Vertellus' Specialty Materials division by approximately 20%.

Trelleborg acquires coated fabrics specialist company Uretek Archer
November 3, 2014 — Trelleborg's engineered fabrics operation in the U.S. (Spartanburg, S.C.; www.trelleborg.com), has acquired the assets and businesses of coated fabrics specialists Uretek Archer LLC Group (New Haven, Conn.; www.uretek.com). The transaction will broaden Trelleborg's range of urethane-coated fabrics, says the company.

BASF and Toda Kogyo form JV for cathode-active materials
October 30, 2014 — BASF SE and Toda Kogyo Corp. (Tokyo, Japan; www.todakogyo.co.jp) will form a joint venture (JV) for cathode active materials (CAM) in Tokyo. The JV will operate under the trade name BASF Toda Battery Materials, LLC. Closing of the agreement and the launch of operations is expected in February 2015. The new JV will have a combined production capacity for CAM and CAM precursors of around 18,000 m.t./yr.

Nippon Shokubai to divest its polyester business to Takiron
October 30, 2014 — Nippon Shokubai Co. (Osaka, Japan; www.shokubai.co.jp) will transfer all shares of its subsidiary, Nippon Polyester Co., to Takiron Co., Ltd. (Tokyo; www.takiron.co.jp). Final agreements will be signed after negotiations of transfer conditions.

Clariant divests its Energy Storage business to Johnson Matthey
October 29, 2014 — Clariant AG (Muttenz, Switzerland; www.clariant.com) has agreed to divest its Energy Storage business to Johnson Matthey Plc. (London; www.matthey.com). The total sale amounts to $75 million. Closing of the transaction is expected in early 2015.

AkzoNobel exits paper chemicals market with divestment of Eka Synthomer JV
October 22, 2014 — AkzoNobel N.V. has divested its 50% JV share in Eka Synthomer Oy to Synthomer for €5 million, following strategic review of the company's portfolio. Eka Synthomer is a non-consolidated JV based in Finland that produces and sells styrene-butadiene latex products for the paper and board industry. ■

Mary Page Bailey

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Economic Indicators

2012 2013 2014

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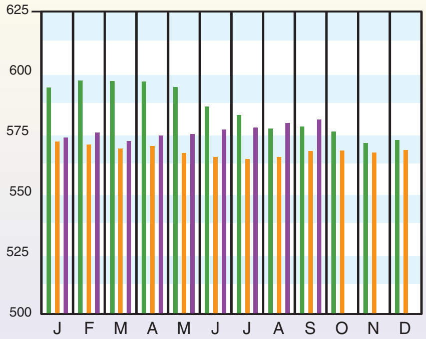
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Sept. '14 Prelim.	Aug.'14 Final	Sept.'13 Final
***CE* Index**	580.2	578.7	567.3
Equipment	704.6	703.7	686.2
Heat exchangers & tanks	650.9	648.7	618.3
Process machinery	668.1	668.0	654.7
Pipes, valves & fittings	877.4	877.1	875.3
Process instruments	413.5	413.9	411.2
Pumps & compressors	939.0	939.3	924.3
Electrical equipment	515.7	516.3	513.7
Structural supports & misc	775.1	773.7	747.1
Construction labor	324.0	320.4	321.7
Buildings	546.5	545.3	533.4
Engineering & supervision	321.9	320.3	324.6

Annual Index:

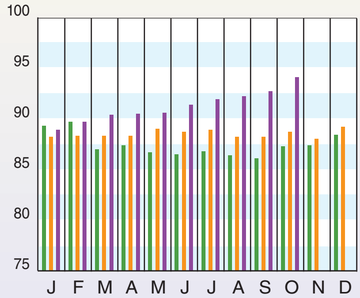
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3



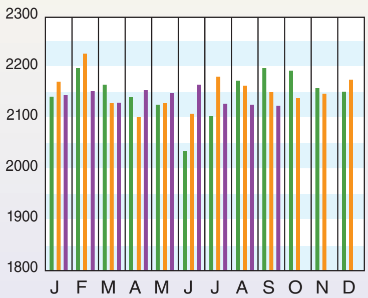
CURRENT BUSINESS INDICATORS*

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2007 = 100)	Oct.'14	=	93.1	Sept.'14	=	92.8	Aug.'14	=	92.5	Oct.'13	=	89.2
CPI value of output, $ billions	Sept.'14	=	2,125.3	Aug.'14	=	2,123.6	Jul.'14	=	2,137.0	Sept.'13	=	2,146.9
CPI operating rate, %	Oct.'14	=	78.0	Sept.'14	=	77.9	Aug.'14	=	77.6	Oct.'13	=	75.7
Producer prices, industrial chemicals (1982 = 100)	Sept.'14	=	296.6	Aug.'14	=	293.9	Jul.'14	=	293.2	Sept.'13	=	298.7
Industrial Production in Manufacturing (2007 = 100)	Oct.'14	=	100.6	Sept.'14	=	100.4	Aug.'14	=	100.2	Oct.'13	=	97.3
Hourly earnings index, chemical & allied products (1992 = 100)	Oct.'14	=	156.3	Sept.'14	=	157.2	Aug.'14	=	156.0	Oct.'13	=	156.6
Productivity index, chemicals & allied products (1992 = 100)	Oct.'14	=	108.1	Sept.'14	=	108.0	Aug.'14	=	108.1	Oct.'13	=	107.6

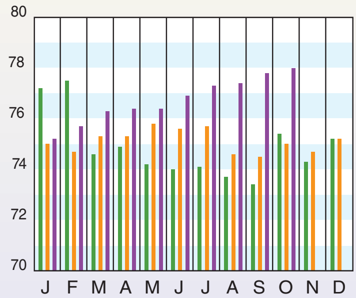
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Current Business Indicators provided by IHS Global Insight, Inc., Lexington, Mass.

HIGHLIGHTS FROM RECENT ACC ECONOMIC DATA

A selection of information from recent Weekly Chemistry and Economic reports from the American Chemistry Council (ACC; Washington, D.C.; www.americanchemistry.com) includes data from the S&P Index for chemical companies, which fell in October by 2.6%, while the wider S&P 500 index rose by 2.3%. From the start of the year, the S&P chemicals index is up 7.1%, while the S&P 500 is up 9.2%.

In other recent chemical-related economic news, U.S. production of major plastic resins was 6.4 billion pounds in September, a total that is 4.2% higher than the same month last year. Year-to-date production for 2014 is slightly lower than the total for the same period last year.

Meanwhile, citing data from the U.S. Bureau of Labor Statistics, ACC said that employment in the business of chemistry rose by 0.3% (2,400 jobs) in September, and citing Census Bureau data, it said sales of chemicals at the wholesale level dropped 2.2% in September.

One recent ACC report stated that U.S. specialty-chemical market volumes ended the third quarter strongly, with a 0.9% gain in September. The September gain followed no change in August, and a 0.7% gain in July. Of the 28 specialty-chemical market segments monitored by ACC, 24 expanded in September. This total is up from 13 expanding in August, the ACC report noted.

Segments experiencing growths of greater than 1.0% included adhesives & sealants, antioxidants, corrosion inhibitors, cosmetic chemicals, flame retardants, foundry chemicals, oilfield chemicals, paint additives, pigments, plastic additives, rubber processing chemicals and textile specialties. ❑

CURRENT TRENDS

The preliminary value for the September *CE* Plant Cost Index (CEPCI; top; the most recent available) rose 0.26% from the final August value, extending the series of monthly increases to six in a row. All four of the major subindices increased in September, with the Construction Cost subsection seeing the largest increase, percentage-wise. The overall September PCI value stands at 2.3% higher than its value from September 2013. Meanwhile, updated values for the Current Business Indicators (CBI) from IHS Global Insight (middle) show that all the indicators increased slightly from the corresponding values for the previous month, except for the Hourly Earnings index, which dipped slightly. ❑

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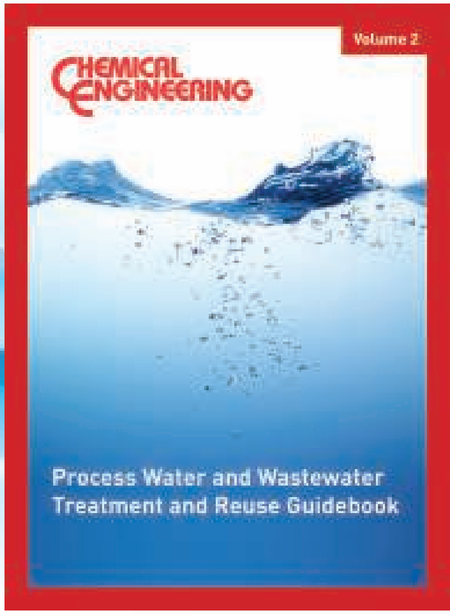

This guidebook contains how-to engineering articles formerly published in *Chemical Engineering*. The articles in Volume 2 provide practical engineering recommendations for process operators faced with the challenge of treating inlet water for process use, and treating industrial wastewater to make it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

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

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- Wastewater: A Reliable Water Resource
- Membranes for Process Water Reuse
- Strategies for Controlling Membrane Fouling
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- Facts at Your Fingertips: Membrane Configurations
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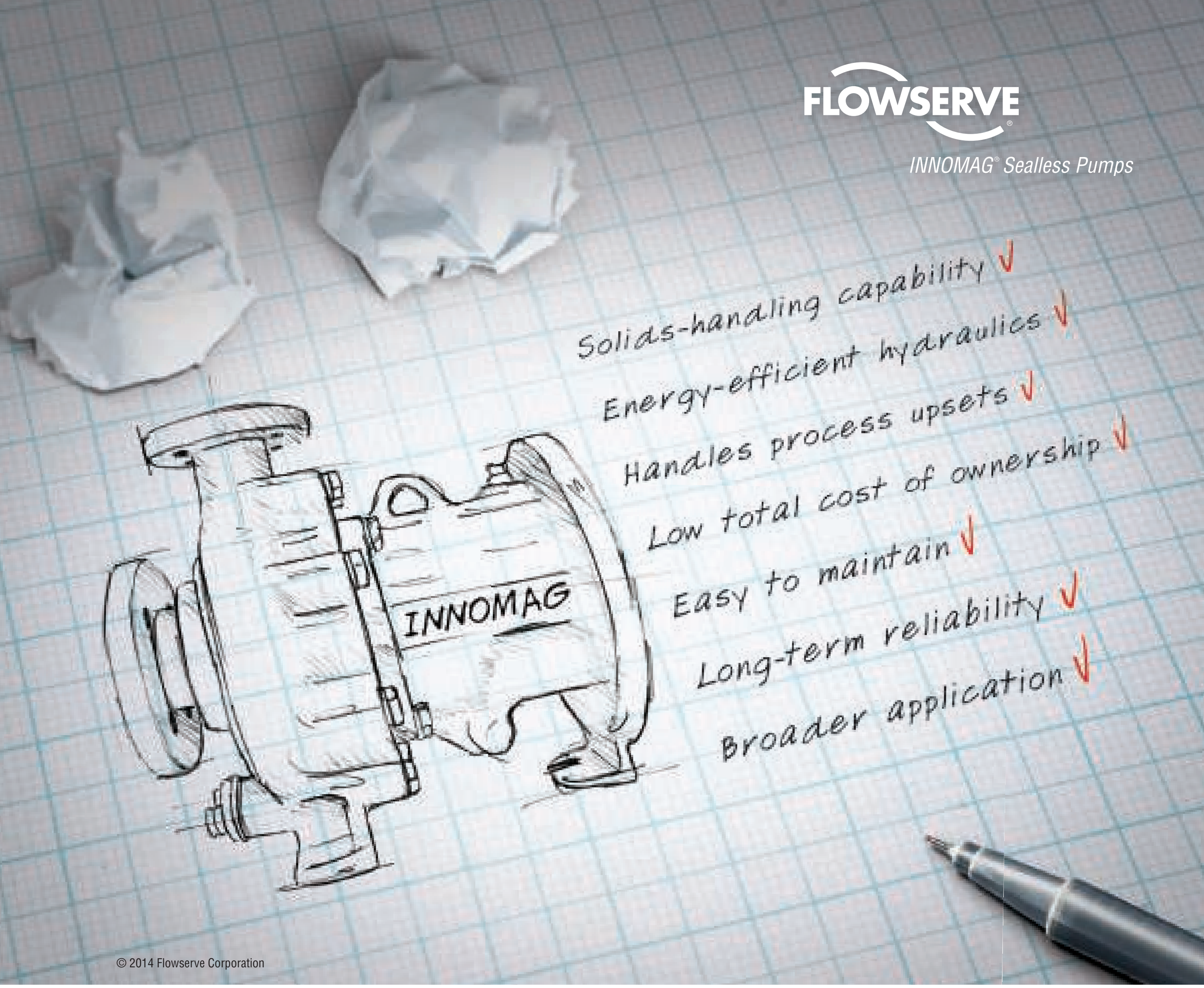

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