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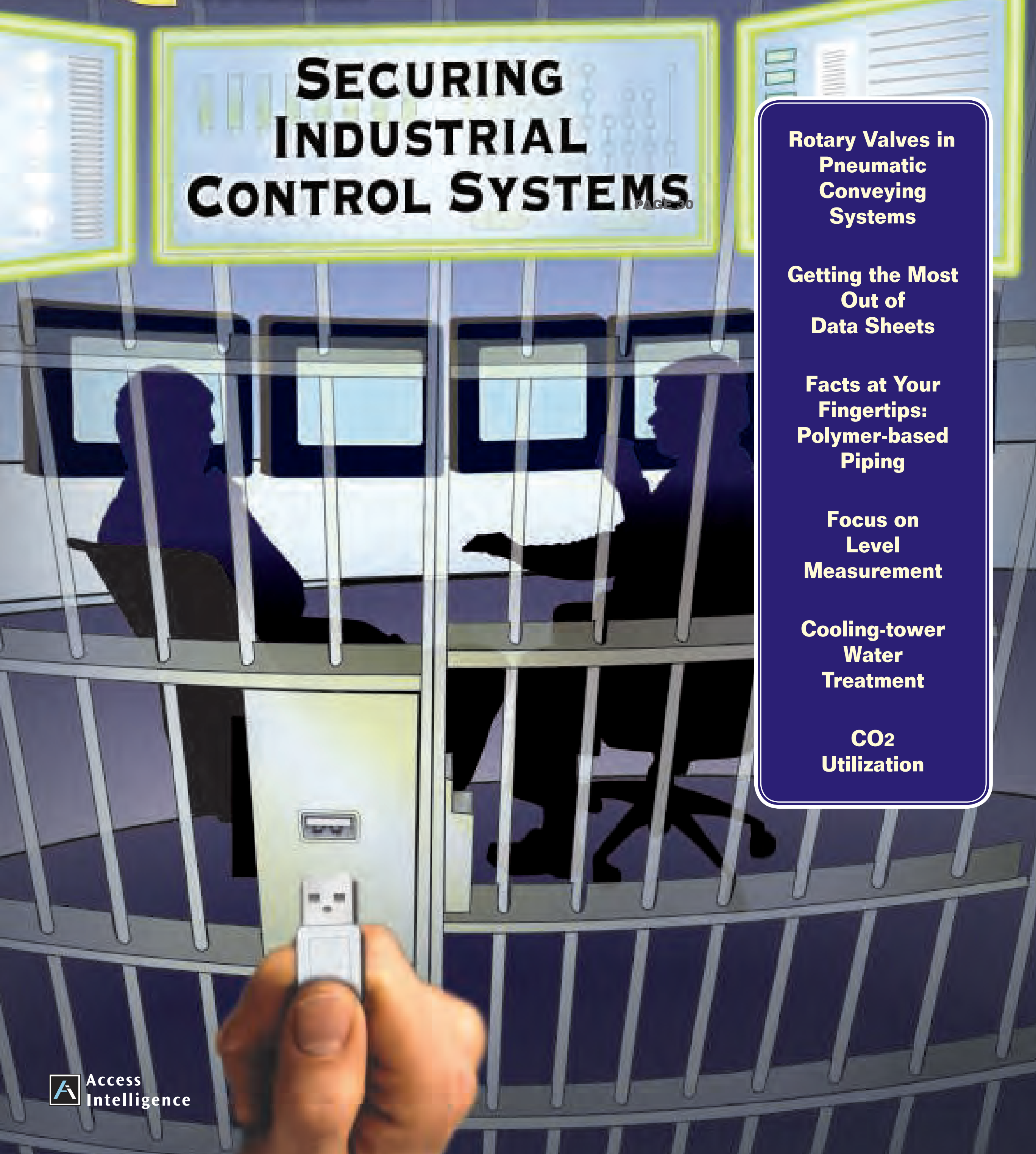

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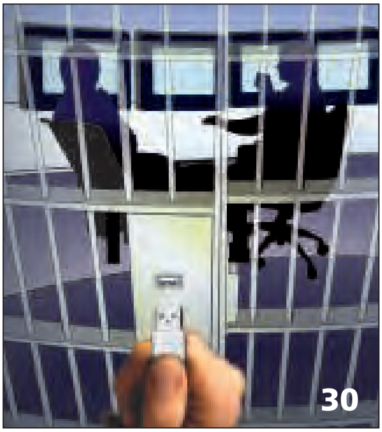

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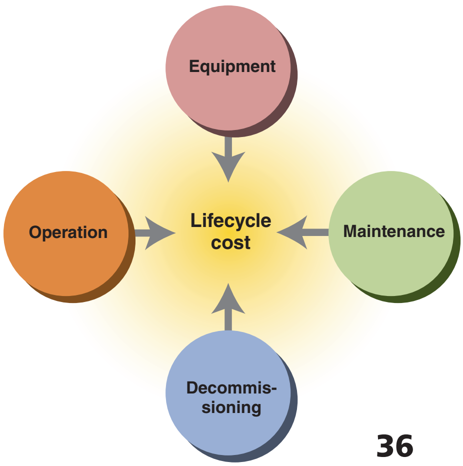

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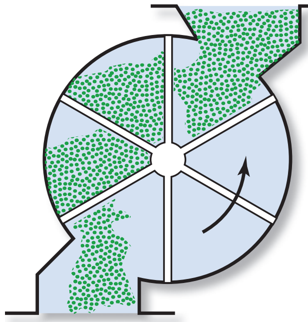

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PUBLISHER

MICHAEL GROSSMAN
Vice President and Group Publisher
mgrossman@accessintel.com

EDITORS

DOROTHY LOZOWSKI
Executive Editor
dlozowski@che.com

GERALD ONDREY (Frankfurt)
Senior Editor
gondrey@che.com

SCOTT JENKINS
Senior Editor
sjenkins@che.com

MARY PAGE BAILEY
Assistant Editor
mbailey@accessintel.com

CONTRIBUTING EDITORS

SUZANNE A. SHELLEY
sshelley@che.com

CHARLES BUTCHER (U.K.)
cbutcher@che.com

PAUL S. GRAD (Australia)
pgrad@che.com

TETSUO SATOH (Japan)
tsatoh@che.com

JOY LEPREE (New Jersey)
jlepree@che.com

GERALD PARKINSON
(California) gparkinson@che.com

MARKETING

MICHAEL CONTI
Marketing Director
TradeFair Group, Inc.
michaelc@tradefairgroup.com

JENNIFER BRADY
Assistant Marketing Manager
TradeFair Group, Inc.
jbrady@che.com

ART & DESIGN

DAVID WHITCHER
Art Director/
Editorial Production Manager
dwhitcher@che.com

PRODUCTION

JOHN BLAYLOCK-COOKE
Ad Production Manager
jcooke@accessintel.com

INFORMATION SERVICES

CHARLES SANDS
Senior Developer
Web/business Applications Architect
csands@accessintel.com

AUDIENCE DEVELOPMENT

SARAH GARWOOD
Audience Marketing Director
sgarwood@accessintel.com

GEORGE SEVERINE
Fulfillment Manager
gseverine@accessintel.com

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BPA

Editor's Page

2013 Kirkpatrick finalists

We are happy to announce the five innovative technologies that have been selected as finalists for the 2013 Kirkpatrick Award for Chemical Engineering Achievement. The winner will be announced on September 25 at an Awards Banquet in Galveston, Tex. during the ChemInnovations Conference and Expo (www.cpievent.com). Here is a brief summary about the finalists:

Braskem — Sugarcane-based ethylene and polyethylene. Braskem has developed a bio-based polyethylene (PE) that, at the end of its life, can be reused, recycled, or incinerated to generate energy, with the main advantage of having neutral carbon emissions. The process starts with sugarcane, which is fermented to ethanol that is in turn converted to ethylene monomer via a high-yield dehydration technology. The bio-ethylene is then polymerized to produce various grades of bio-PE. The polymers can be transformed, using existing equipment, into products for a wide-range of applications, including blow molding, injection molding and films.

Eastman Chemical Co. — Perennial wood. Alternatives to wood as a building material have been developed to overcome the disadvantages of using real wood, such as shrinking, swelling, rotting and warping. But, many say that there is no substitute for real wood. Eastman has commercialized a wood that has been chemically modified through acetylation to offer a real-wood alternative that is said to be three times more stable than unmodified wood. The acetylation modification permanently modifies the wood's cellular structure while leaving no toxic substances in the wood.

Genomatica — Bio-based butanediol. Working with its partner DuPont Tate & Lyle BioProducts, Genomatica has successfully commercialized the production of bio-based butanediol (BDO). A total of 5-million lb of product was produced in only five weeks. According to the company, this is the first time BDO has been produced at commercial scale from renewable feedstocks. The bio-based process is said to have a smaller environmental footprint and is designed for better overall economics than conventional BDO made from fossil fuels. Genomatica credits its fast scaleup success, in part, to good chemical engineering discipline.

Pacific Northwest National Laboratory (PNNL) — Propylene glycol from renewable resources (PGRS). Up to 2.5-billion lb of petroleum are consumed each year to meet worldwide demand for propylene glycol (PG). Scientists at PNNL have developed novel catalysts for producing PG from renewable sources. PGRS is said to be the world's first industrial-scale process for producing U.S. Pharmacopeia-grade PG from renewable plant sources, utilizing glycerol obtained from soybean processing. The process is economically competitive with petroleum-based routes, and results in up to 61% reduction in greenhouse gas emissions, according to PNNL. The technology was licensed to Archer Daniels Midland Co., which designed, engineered and commissioned a new 100,000 metric ton per year production facility.

Rive Technology — Molecular Highway catalyst technology. Innovations in fluid catalytic cracking (FCC) catalysts have largely focused on improvements to matrices, binders and additives rather than on the zeolite component. Rive has focused on the zeolite, and has developed a mesoporous zeolite technology for improved mass transfer into and within the zeolite crystals. This technology makes traditional zeolite cracking catalysts more accessible to large hydrocarbon molecules and thereby allows increased production of gasoline and diesel fuels. ■

Dorothy Lozowski, Executive Editor

Letters

Chopey scholarship awarded

The 2013 Nicholas P. Chopey Scholarship for Chemical Engineering Excellence has been awarded to Adam Freitag, who is a third-year chemical engineering student at Rutgers, The State University of New Jersey (New Brunswick, www.rutgers.edu). Freitag is president of Tau Beta Pi's (National Engineering Honor Society) N.J. Beta Chapter. He is involved with the Materials Science & Engineering Dept. and has received the Junior Merit Award for Chemical Engineering at Rutgers. Freitag graduated from North Hunterdon High School (Annandale, N.J.).

About the scholarship

Bringing recognition to the chemical engineering profession and striving to continually advance that profession have been goals of *Chemical Engineering* magazine since its founding more than 110 years ago in 1902. To help advance those goals, *CE* established the annual Chopey Scholarship for Chemical Engineering Excellence in late 2007. The award is named after Nicholas P. Chopey, the magazine's former Editor-in-Chief who made many valuable and long-lasting contributions to *CE* over the 47 years that he devoted to it. To honor his contributions to the chemical engineering profession, *CE* established the scholarship in his name.

Applicant qualifications. The scholarship is awarded to current third-year students who are enrolled in a fulltime undergraduate course of study in chemical engineering at one of the following four-year colleges or universities:

- Columbia University
- Rutgers University
- SUNY Buffalo
- University of Kansas
- University of Virginia

The scholarship is a one-time award. The program utilizes standard Scholarship America recipient-selection procedures, including the consideration of past academic performance and future potential, leadership and participation in school and community activities, work experience, and statement of career and educational goals.

Donations. Donations can be made to the scholarship fund, by sending a check to the following address:

Nicholas P. Chopey Scholarship Fund
Attn: Jennifer Brady
Chemical Engineering
11000 Richmond Ave., Suite 690
Houston, TX 77042

Checks should be made out to Scholarship America with "Nicholas P. Chopey Scholarship Program" in the memo area.

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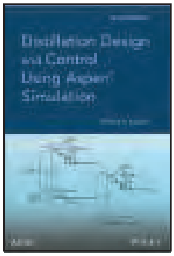
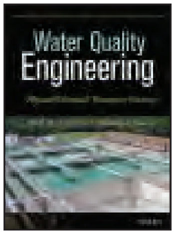


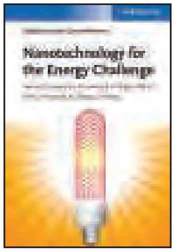
Distillation Design and Control Using Aspen Simulation. 2nd ed. By William Luyben. John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030. Web: wiley.com. 2013. 489 pages. $130.00.

Engineering Material 2: An Introduction to Microstructures and Processing. 4th ed. By D.R. Jones and Michael Ashby, Elsevier Inc., 225 Wyman Street, Waltham, MA 02144, Web: elsevier.com. 2013. 576 pages. $69.95.



Water Quality Engineering: Physical/Chemical Treatment Processes. By Mark M. Benjamin and Desmond F. Lawler. John Wiley & Sons Co., 111 River Street, Hoboken, NJ 07030. Web: wiley.com. 2013. 904 pages. $170.00.

Chemistry of Fossil Fuels and Biofuels. By Harold Schobert, Cambridge University Press, University Printing House, Shaftesbury Road, Cambridge CB2 8BS, U.K. Web: cambridge.org. 2013. 497 pages. $115.00.



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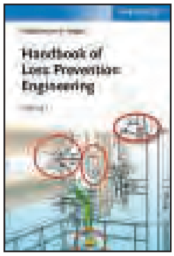
Industrial Process Scale-up: A Practical Innovation Guide from Idea to Commercial Implementation. By Jan Harmsen. Elsevier Inc., 225 Wyman Street, Waltham, MA 02144, Web: elsevier.com. 2013. 112 pages. $64.95.



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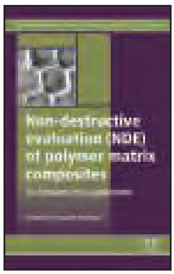
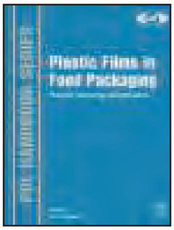
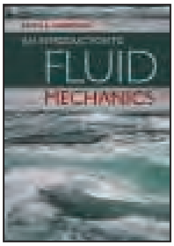


Advanced Water Injection Low Permeability Reservoirs. By Ran Xinquan. Gulf Publishing Co., Gulf Publishing Co., 2 Greenway Plaza, Suite 1020, Houston, TX 77046. Web: gulfpub.com. 2013. 264 pages. $99.95.

Plastic Films in Food Packaging. Edited by Sina Ebnesajjad. Elsevier Inc. 225 Wyman Street, Waltham, MA 02144. Web: elsevier.com. 2013. 384 pages. 2013. $249.00.



Industrial Sampling Systems: Reliable Design & Maintenance for Process Analyzers. By Tony Waters. Swagelok Co., 29500 Solon Road, Solon, OH 44139. Web: industrial-sampling-systems.com. 2013. 750 pages. Pricing available from local Swagelok sales and service centers.



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Introduction to Fluid Mechanics. By Faith A. Morrison. Cambridge University Press, University Printing House, Shaftesbury Road, Cambridge CB2 8BS, U.K. Web: cambridge.org. 2013. 940 pages. $135.00.

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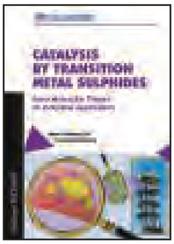
Gas Chromatography and 2D Gas Chromatography for the Petroleum Industry. By Fabrice Bertoncini, Marlene Courtiade-Tholance and Didier Thiébaut. Editions Technip, 25 rue Giroux, 75015, Paris, France. Web: editionstechnip.com, 2013. 368 pages. $72.00.

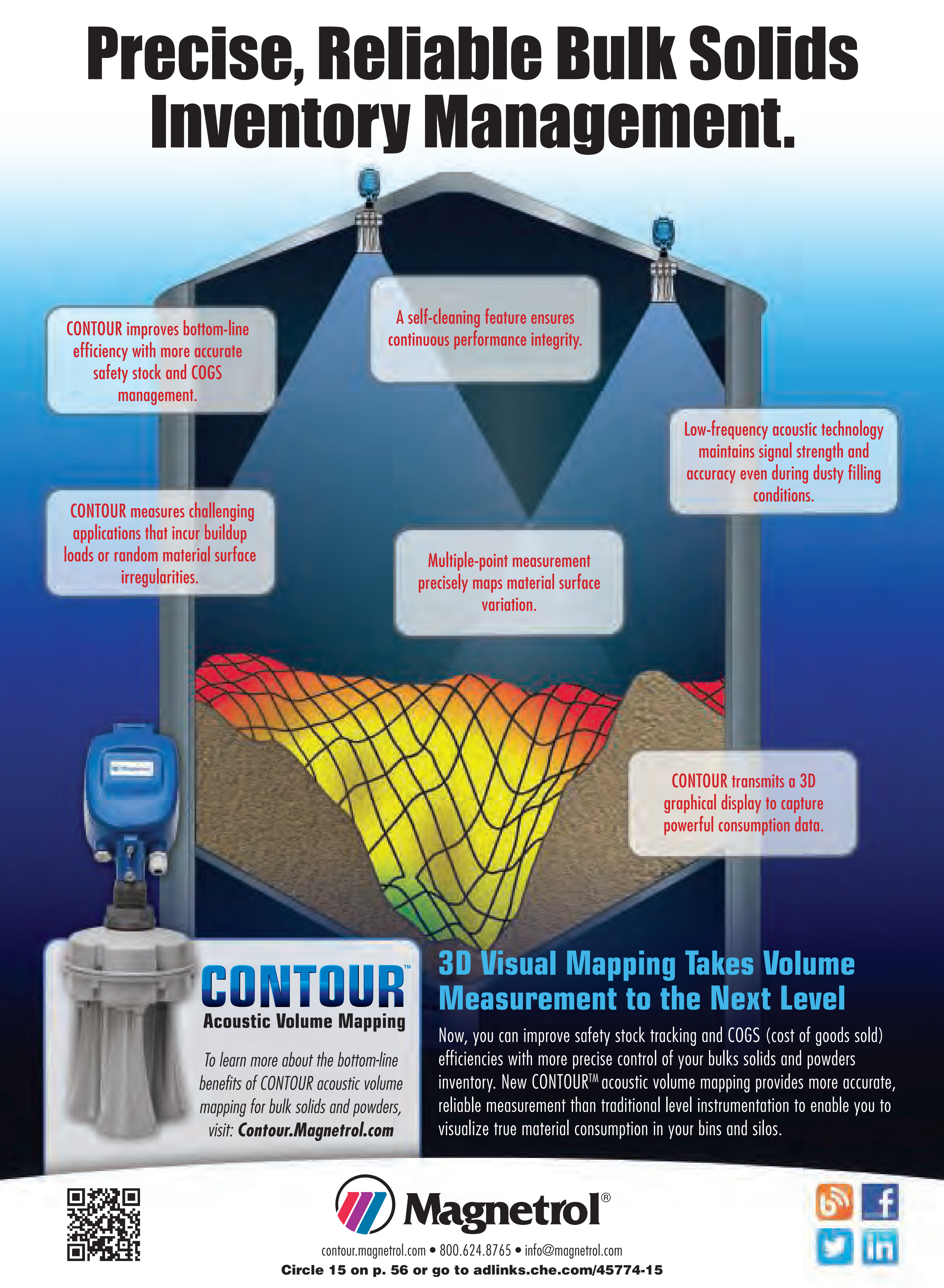
Waste to Energy Conversion Technology. Edited by Naomi B. Klinghoffer and Marco J. Castaldi. Woodhead Publishing Ltd., 80 High Street, Sawston, Cambridge CB22 3HJ, U.K. Web: woodheadpublishing.com. 2013. 256 pages. $205.00.



Catalysis by Transition Metal Sulphides: From Molecular Theory to Industrial Application. Edited by Hervé Toulhoat and Pascal Raybaud. Editions Technip, 25 rue Giroux, 75015, Paris, France. Web: editionstechnip.com, 2013. 832 pages. $130.00. ■

Scott Jenkins

Editor's Note: If you would like to review a recently published book in your area of expertise as a guest reviewer, please contact Scott Jenkins, senior editor, *Chemical Engineering* magazine (sjenkins@che.com).



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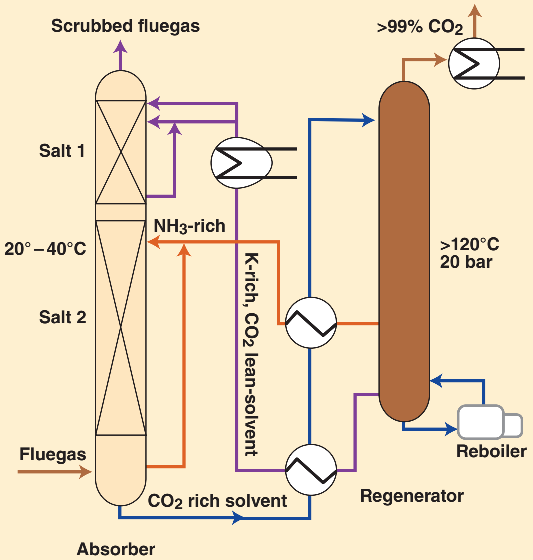
A salty way to scrub CO_2



Ammonia is a promising candidate for scrubbing carbon dioxide from fluegas, since each ammonia molecule can absorb one molecule of CO_2, whereas amine absorbers require two molecules to do the same job. However, because ammonia is volatile, the fluegas must be cooled to about 10°C. This requires a lot of electrical energy, points out Indira Jayaweera, a senior staff scientist with SRI International (Menlo Park, Calif.; www.sri.com). Also, the absorption rate of the ammonia is not fast enough at this low temperature.

Jayaweera is program manager for a new ammonia-based, mixed-salt process that avoids these problems of the so-called chilled ammonia route. In SRI's process (flowsheet) a fluegas stream is injected into the bottom of an absorption column and contacted with a counter-current aqueous solution of ammonium and potassium carbonates. The reaction takes place at 20–40°C, so the absorption rate is about five times that of chilled ammonia, says Jayaweera. The main role of the potassium carbonate is to reduce the vapor pressure, to avoid losing the more-volatile ammonia. Absorbent in the lower part of the column has a high percentage of ammonium carbonate, while the upper part has more potassium carbonate. The main reaction takes place in the bottom of the column and unreacted ammonia flows upward and is redissolved in the upper part. Jayaweera adds that this ammonia also acts as a catalyst to speed up the reaction between the CO_2 and the potassium carbonate, which normally has a low rate of absorption.

The process is driven by the regenerator, where CO_2 is released from the solvent at about 120°C. Jayaweera notes that the gas is released as dry CO_2 at a pressure of 20–40 bars, so it could be used for enhanced oil recovery, without further treatment. The solvent is separated by heat and pressure into ammonia- and potassium-rich streams, the former being recycled to the bottom of the absorption column and the latter to the top.

In laboratory tests the system has captured 99% of the available CO_2, says Jayaweera, and the ammonia can achieve a CO_2 load as high as 15 wt.%, as compared to less than 5 wt.% for amines. She estimates that the cost of a commercial unit could be as low as one-half the current cost of about $60 per metric ton (m.t.) of captured CO_2 for an amine-based process. SRI is seeking partners to do a 100 cfm (~0.1 MW) demonstration of the technology.

These scavengers of water pollutants have a magnetic attraction

A process that uses magnetic nanoparticles, coated with a reactive material, to clean up contaminated water for human use is being developed at Stanford University (Stanford, Calif.; stanford.edu). The nanoscavengers, as they are called, are distributed in the water to kill pollutants, then are recovered magnetically for re-use.

Stanford's particles are discs that consist of a layer of titanium, sandwiched between layers of pure iron, with an outer coating of reactive material. The discs, measuring about 150-nm dia. by 60-nm thick, are fabricated by thermal evaporation.

The novel feature is that the direction of the magnetic force in the top and bottom layers point in opposite directions, thereby canceling the magnetic properties of the material, says Mingliang Zhang, of the Stanford School of Engineering. However, when a strong electromagnetic field is activated the opposing magnetic forces are aligned, making the particles strongly magnetic.

So far the researchers have used silver-coated nanoparticles to achieve 99.9% destruction of *E.coli* and *E. hirae* bacteria, and are now testing titanium dioxide-coated particles for photocatalytic degradation of trichloroethylene (TCE) and *N*-nitrosodimethylamine (NDMA). The researchers' goal is to create nanoscavengers that carry several reactants for recycling water in developing nations or for treating water in arid climates.

ODC for Cl_2 production

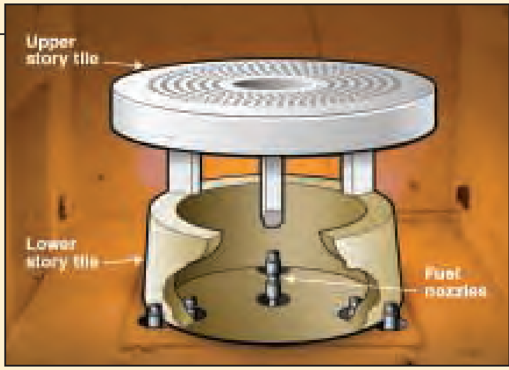
Last month, ThyssenKrupp Uhde GmbH (Dortmund; www.uhde.eu) and Bayer MaterialScience AG (BMS; Leverkusen, both Germany; www.bayermaterialscience.com) commercially launched — worldwide — the oxygen depolarized cathode (ODC) technology, which BMS and ThyssenKrupp Uhde/UhdeNora developed to improve the efficiency of membrane chlor-alkali plants. By replacing the electrode that normally produces H_2 in the membrane process by an oxygen-depolarized cathode, O_2 suppresses the formation of H_2. As a result, the plant produces only caustic and Cl_2, and the electricity consumption for the process is reduced by as much as 30%, say the companies (for more details, see *CE*, May 2007, pp. 50–55). The ODC technology has undergone two years of industrial-scale operation in a demonstration plant at Bayer's Krefeld-Ürdingen site (*CE*, May 2010, p. 11).

Oil hydrogenation

BASF Catalysts LLC (Iselin, N.J.; www.basf.com/catalysts) has developed new nickel

(*Continues on p. 12*)

Note: For more information, circle the 3-digit number on p. 56, or use the website designation.



Burner technology enables reduced NOx with short flame length

To comply with increasingly stringent regulations for NOx emissions, operators of industrial plants often turn to low-NOx burners to avoid much more costly post-combustion treatment approaches like selective catalytic reduction (SCR). But low-NOx burners are plagued by significant losses in efficiency and process throughput.

ClearSign Combustion Corp. (Seattle, Wash.; www.clearsign.com) has developed patent-pending technologies to address this issue. The technologies can effectively reduce the formation of NOx to less than 5 ppm during combustion without compromising fuel efficiency. ClearSign's Electrodynamic Combustion Control (ECC), uses computer-controlled electric fields to manipulate the movement of charged particles within and around burner flames. The high-voltage, low-power fields are pulsed to precisely control the physics and chemistry of the flame, including its shape and heat-transfer properties, explains ClearSign CEO Rick Rutkowski. ECC can be applied to new or existing burners.

ClearSign has also developed a novel burner architecture with an upper and lower tier (diagram) that allows the anchor position of the flame to be manipulated so that a large amount of fluegas is entrained within the combustion gas. The effect of the entrained fluegas is to dilute ionic and free-radical species that would otherwise react to generate NOx. Because the NOx-forming species are less likely to come into contact and react, lower levels of NOx are formed in the combustion. The so-called Duplex burner can maintain a stable flame over a large operating range (natural gas through propane) even with low levels of excess oxygen (1–3%) while dramatically reducing flame length, says Rutkowski.

Using ClearSign's ECC and Duplex technologies, operators can realize overall efficiency gains of 20–30% and NOx emissions less than 5 ppm. In addition, particulate matter generated during combustion agglomerates into pieces that are easy to remove. Major applications include petroleum refining, electric power generation, ethane cracking and other hydrocarbon processing.

ClearSign has demonstrated ECC with the Duplex burner at scales approaching 250,000 Btu/h, and is now looking for partners in the burner manufacturing space to help move the technology toward commercialization.

Improved corrosion control in refinery steam systems

GE Power & Water (Trevose, Pa.; www.ge.com) has introduced a novel, dual-pronged approach to corrosion inhibition for boiler and steam-condensate systems in petroleum refineries. The technology is designed to prevent attack by acidic species on steam-system surfaces, providing reliability to the refining process and helping to maximize profitability.

Tradenamed Steamate Low Salt Amine (LSA), this new series of products involves a specially designed set of volatile amines to neutralize acidic contaminants, primarily CO_2, in steam condensate. In addition, the Steamate LSA series products can include a unique, volatile, surface-corrosion inhibitor, referred to as a "polyamine," that forms a robust barrier film on boiler system surfaces to restrict access of corrosive species.

Using newly developed chemical structures, the volatile neutralizing amines raise the pH level of the acidic steam condensate into the mild alkaline range (~9), which is the ideal range for protecting the steel and copper alloys used in steam condensate systems, explains Tony Rossi, GE product manager for boiler chemicals. Further, GE uses specialized modeling to select amines based on the property of salt-point temperature — amines with lower salt-point temperatures have reduced potential to form corrosive amine-chloride salt deposits on the interior of crude-oil distillation towers, where boiler steam is used to improve fractionation efficiency.

Meanwhile, GE's polyamine barrier film — which Rossi likens to a protective wax finish on a washed automobile — also inhibits dissolved oxygen pitting, and is compatible with the new neutralizing amines used in GE's integrated boiler and process-steam treatment. "An advantage of this protective barrier is that it is more volatile than traditional filming corrosion inhibitors," says Rossi, "so it leaves the boiler very efficiently with the steam, and provides very effective coverage of the steam-

(Continues on p. 15)

(Continued from p. 11)

catalyst and activated clay technology for the hydrogenation of edible oils and fatty acids that improves activity with the same level of metal. The greater catalyst activity allows food processors to shorten batch times, or run reactions at lower temperatures, which reduces formation of "trans fats" in processed oils. Also for the edible oil market, BASF has developed an acid-activated clay for the oil purification process. The more active clay allows users to employ lower doses of clay to achieve the same level of color removal from the oil, the company says. The sulfuric-acid-activated clay is available in two grades, one for standard oils and another for tougher-to-bleach oils.

Graphite HEX

Last month, SGL Group (Wiesbaden, Germany; www.sglgroup.com) launched the world's largest graphite-plate heat exchanger, which provides flowrates of up to 250 m^3/h, the company says. Used for heating or cooling of corrosive liquids, the large Diabon plate heat exchangers are said to require up to 75% less heat exchanger area for the same performance, compared to annular-groove, block or shell-and-tube heat exchangers. The new exchangers are available, globally, through SGL's partner, Alfa Laval AB (Lund, Sweden; www.alfalaval.com).

Benign fertilizer

Sandia National Laboratory (Albuquerque, N.M; www.sandia.gov) researcher Kevin Fleming has developed a formulation for the widely used crop fertil-

(Continues on p. 14)

A gas turbine with low NOx emissions

NEDO (see story on p. 14) and Hitachi Ltd. (Tokyo, www.hitachi.com) have developed a new combustion technology that could reduce the emissions of oxides of nitrogen (NOx) to below 10 ppm without the addition of diluents. As part of the CCS-IGCC project (carbon capture and storage — integrated coal gasification, combined cycle), the researchers have developed a "multi-hole, coaxial jet-flow burner" for use in a gas turbine combustor. The burner enables stable combustion of the H_2-rich fuel and NOx emissions are suppressed below the 70 ppm required by environmental regulations without having to add diluents, which normally reduce the power-generation efficiency. Tests have been performed at the facility's "Eagle" pilot plant using actual gas from a coal gasifier. The pilot unit has six cans of multi-hole jet flow burners. The researchers also confirmed stable operation of the system, all the way from turbine startup to maximum power generation, and during the fuel change from liquid fuel (at startup) to coal-gasified gas. This is claimed to be first real application of a CCS-IGCC plant that enables both reduction of NOx emissions and also high-efficiency power generation.

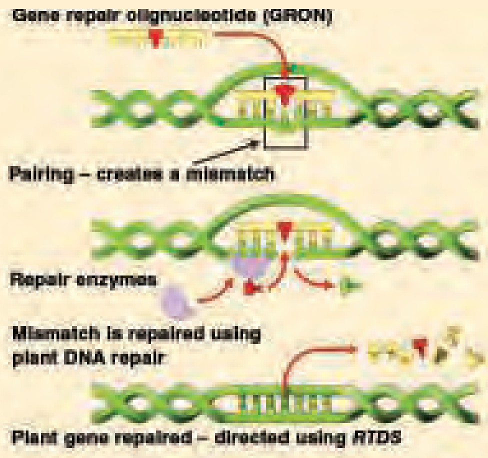
Nanowires improve the properties of metal composites

Freestanding nanowires exhibit ultrahigh elastic-strain limits (of up to 7%) and yield strengths. However, it has been difficult to exploit their properties in bulk composites, due to the mismatch between the elasticity of the nanowires and the elasticity of the metals that form the matrix. The nanowires will experience an elastic deformation of several percent, but normally the metals that form the matrix can stretch elastically to no more than 1%. Beyond that, the matrix deforms plastically.

Now, a team from Australia, China, Japan and the U.S. has produced a metal nanocomposite — a combination of Nb nanowires with a NiTi shape-memory alloy — that allows the mechanical properties of nanowires to be exploited in bulk materials. "The trick is with the NiTi matrix — a shape-memory alloy with a special property in its martensitic transformation," says a team member, professor Yinong Liu, head of Mechanical and Chemical Engineering at the University of Western Australia (www.uwa.edu.au). "The transformation can produce a deformation compatible with the elastic deformation of the nanowires without plastic damage to the composite structure. This allows the nanowires to bear the high load and be super strong, " he says.

The team developed a composite with a quasi-linear elastic strain of over 6%, a low Young's modulus of about 28 GPa and a high yield strength of about 1.65 GPa. The team says this breakthrough opens the door for many new applications. The low Young's modulus matches that of human bone, making the composites suitable for medical implants. The composites could also lead to improvements in properties of solid materials, such as electronic, optoelectronic, piezoelectric, piezomagnetic, photocatalytic and chemical-sensing properties

A biotech process that might benefit sharks



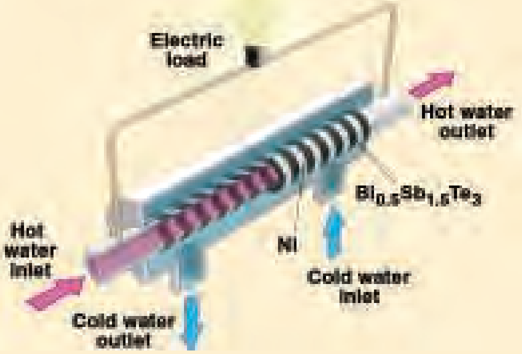
Squalane, an emollient used in cosmetics, will be the first product of a biotechnology pilot plant now being started up by Nucelis Inc. (San Diego, Calif.; www.nucelis.com), a spin-off from Cibus (also of San Diego). The plant will use Cibus' Rapid Trait Development System (RTDS), a new gene-editing technology, to enable naturally occurring yeast to increase their production of squalene, the precursor of squalane.

RTDS (diagram) differs from genetically modified organisms (GMO) in that it does not involve the introduction of foreign genes into a microorganism, says Sean O'Connor, president of Nucelis. Instead, the organism's own natural repair mechanism is triggered by the introduction of oligonucleotides, which changes the way the cells work. After doing their job, the oligonucleotides are broken down by the cells within 90 minutes. O'Connor adds that the process is "more precise than GMO."

Nucelis has focused on squalene initially because it fits in the company's plan to make products through sustainable processes, using low-value feedstocks that are outside the food chain. At present the main sources of squalene are olive oil and sharks' livers. Nucelis produces squalene from glycerol, a low-cost, unwanted byproduct of biodiesel fuel, then converts it to squalane by conventional hydrogenation. The product is 99.7% pure, versus a purity of 95-99% for the shark product and 90–95% for olive oil, says O'Connor, and the process "is competitive in the market."

Initially, the pilot plant is using two 200-L fermenters. Nucelis plans to add two more 200-L fermenters next year and two more in 2015, for a total capacity of 1,200 L.

Using low-temperature waste heat to make power



New Energy and Industrial Technology Development Organization (NEDO; Kawasaki City; www.nedo.go.jp) and Panasonic Corp. (Osaka, both Japan; panasonic.net) have begun testing a new type of power-generation system that uses anisotropic solid-state composites that produce an electrical current when a temperature gradient is applied. A prototype has been installed at Kyoto City Northeastern Clean Center where it will recover waste heat from a 700-ton/d waste incinerator and make electricity. The incinerator generates 232.82 GJ/d of heat that cannot readily be recovered by conventional methods due to the low temperature of the exhaust stream.

Panasonic's thermoelectric device consists of a tube with alternating layers of slanted discs composed of bismuth telluride-based thermoelectric materials ($Bi_{0.5}Sb_{1.5}Te_3$) and nickel metal. This tubular composite of $Bi_{0.5}Sb_{1.5}Te_3$/Ni with cylindrical anisotropy introduces effective thermoelectric tensors so that a temperature gradient along the axis causes an electric current to flow transversely. The tubular configuration allows for direct and efficient heat transfer from fluid heat sources.

Tests are being performed on a compact unit made of four parallel tubes, each 100-mm with diameters of 10 mm (I.D.) and 14 mm (O.D.). The unit generates 10 W of power (0.5 V × 20 A) when the hot water inlet temperature is 90°C, and the cooling water inlet temperature is 10°C.

This NEDO project, which started in July 2011 and runs through February 2014, is ultimately targeting a power generation of more than 400 W/m^3 from low-temperature unused heat, which is eight times more than existing thermoelectric devices. The power generated per installed space is nearly twice that from solar panels, says Panasonic.

(*Continued from p. 12*)

izer ammonium nitrate that prevents its use in improvised explosive devices (IED), while still maintaining its ability to fertilize crops. Taking advantage of the weak binding between the ions in ammonium nitrate, the Sandia researchers developed a formulation that includes iron sulfate. The iron sulfate renders the ammonium nitrate undetonable when mixed with fuel, as in an explosive device. In the presence of iron sulfate, a waste product from steel production, the ions "trade," forming iron nitrate and ammonium sulfate, which cannot be made to explode. The iron sulfate has added benefits for soil health, creating less alkaline soils in locations such as Afghanistan, where a non-detonable fertilizer would help prevent IED attacks.

Cold boiling

Researchers at the University of Sheffield (U.K.; www.sheffield.ac.uk) are developing a process that causes water to evaporate without boiling. The patent-pending process involves injecting hot microbubbles to a thin layer of liquid. The method has been demonstrated for separating water from methanol, and now the researchers are working on a pilot project with Carbon Sequestration Ltd. to dewater whey, which is commonly used as animal feed. If whey is overheated during dewatering, it loses its nutritional value. ❑

IMPROVED CORROSION CONTROL (*Continued from p. 12*)

condensate system when fed to the boiler feedwater."

Use of Steamate LSA has commenced in a small number of commercial refineries, and the results have been positive, Rossi says. For example, because of the lower risk of corrosion and deposits in distillation towers, petroleum refiners are able to run at lower top temperatures to maximize yields of middle distillates, such as diesel and gasoline, from crude oil.

Bio-butanol scaleup moves ahead with trials . . .

In April development tests, Cobalt Technologies (Cobalt; Mountain View, Calif; www.cobalttech.com) produced *n*-butanol at the fermentation scale of 100 m^3 per run, demonstrating lower production cost than butanol produced from petroleum. This represents production that is a factor of 10 larger than previous trials conducted at the National Renewable Energy Laboratory (NREL; Golden, Colo.; www.nrel.gov), and one-tenth of full-scale commercial production. The trials were conducted at a site in Florida owned by biofuels company LS9 Inc. (San Francisco, Calif.; www.ls9.com)

Cobalt is exploring opportunities in the U.S. for retrofitting an existing corn ethanol plant to eventually produce butanol from available biomass, explains Cobalt CEO Bob Mayer.

Developed using a range of biomass sources, including sugarcane bagasse, woody biomass, and other agricultural residuals, the Cobalt bio-butanol process involves a carbohydrate extraction process that is integrated with fermentation and distillation. Cobalt employs fermentation strains specially selected for their ability to metabolize both five- and six-carbon sugars. The company has developed proprietary bioreactor technology that will allow continuous fermentation, as well as an advanced batch process.

By combining integrated extraction, continuous fermentation and strain selection technologies with an efficient, reduced-energy distillation process and low-cost biomass, the company can produce butanol at savings of 40–60% compared to petroleum-derived butanol, Mayer says.

. . . and a bio-butadiene plant is planned

On the heels of its successful scaleup of bio-butanol, Cobalt is looking for pathways to use that molecule as a building block for other products. The company has announced plans to build the first bio-butadiene plant in Asia. Projected to come onstream in 2017, the plant will utilize traditional chemical catalysis technology to take bio-butanol to butadiene.

Cobalt CEO Bob Mayer says the company is developing an intellectual property package for the bio-butadiene that will be marketed worldwide. As a key raw material for automobile tires and other products, butadiene's worldwide market is eight times larger than the $5-billion annual market for butanol, Mayer notes. ■

CO_2 UTILIZATION

Researchers are developing new technologies for using CO_2 as a feedstock to make a variety of chemicals

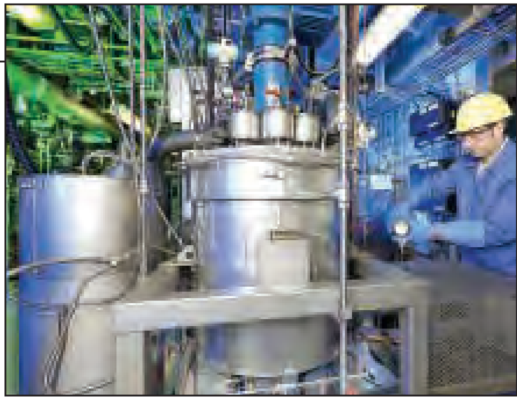


FIGURE 1. This miniplant in Leverkusen, Germany is being used to develop CO_2-containing polymers for making polyurethane foam used in cars and furniture

On May 9, atmospheric carbon dioxide levels surpassed 400 ppm in Mauna Loa, Hawaii for the first time since measurements began there in 1958. This concentration is well above the 280 ppm levels occurring prior to the Industrial Revolution of the 19th century, according to the Scripps Institution of Oceanography, University of California (San Diego, Calif.; scripps.ucsd.edu). Today's rate of increase of CO_2 into the atmosphere is more than 100 times faster than the increase that occurred when the last ice age ended, says Scripps.

Efforts to stem the flow of this greenhouse gas (GHG) into the atmosphere are becoming a priority in some countries, which are investing considerable funding for R&D projects in carbon capture and storage (CCS; see, for example *Chem. Eng.*, May 2008, pp. 28–36). Targeting the main culprits — combustion of fossil fuels for power generation or cement production — CCS projects over the last 20 years have primarily focused on capturing CO_2 from fluegas, and then injecting the pressurized CO_2 underground or into wells for enhanced oil recovery (EOR).

More recently, another branch of R&D has begun to blossom — carbon capture and utilization (CCU) — whereby the CO_2 captured from fluegas is used as a feedstock to make chemicals, such as polymers, methanol and even the key chemical building block, CO. Chemists and chemical engineers around the world are trying to exploit a variety of technologies from their toolboxes, such as developing new polymerization catalysts, electrochemical and photochemical processes, biotechnological methods and others, in order to not only make use of the CO_2, but also to reduce the amount of petroleum-derived feedstock needed to produce products.

In Germany, for example, the Federal Ministry of Education and Research (BMBF; Bonn; www.bmbf.de) has recently earmarked €100 million for "Technologies for Sustainability and Climate Protection — Chemical Processes and Use of CO_2," with the objectives of lowering dependency on crude oil and natural gas, using CO_2 as a raw material, doubling energy productivity by 2020, and reducing CO_2 emissions by up to 40% by 2020. Among the 33 funded projects for the 2009–2015 timeframe are 11 for CO_2 utilization and seven for making chemicals.

The U.S. Dept. of Energy (DOE; Washington, D.C.; www.energy.gov), too, has recently added CCU to its pallet of technologies receiving funding through its National Energy Technology Laboratory (NETL; Pittsburgh, Pa.; www.netl.doe.gov),. The DOE is also funding startup companies struggling to commercialize CCU technologies. Some of these projects are described below.*

Polymers with CO_2 built-in

In February, the world's first large-scale production of polypropylene carbonate (PPC) polyol using waste CO_2 as a raw material commenced. Partially funded by a three-year, $25-million grant from the DOE's Office of Fossil Energy, the PPC run was conducted by Novomer Inc. (Waltham, Mass.; www.novomer.com) in collaboration with Albemarle Corp. (Orangeburg, S.C.; www.albemarle.com), and tested Novomer's catalyst technology.

The batch run produced seven tons of finished polymer — a PPC diol with a molecular weight of 1,000 g/mol — that is being used to accelerate product qualification and adoption in a wide range of polyurethane applications, says Novomer's executive vice president, Peter Shepard. The PPC is made by the catalytic copolymerization of CO_2 and propylene oxide. Containing up to 40 wt.% CO_2, the PPC can be tailored to a range of material characteristics, from solid plastics to soft, flexible foams, depending on the length of the polymer chains.

Novomer's homogeneous, cobalt-based catalyst is 300 times more active than previous systems developed to synthesize aliphatic polycarbonates. This enables the process to operate at much milder temperatures of 35–50°C, says Shepard. Novomer's process takes place in the liquid phase at 150–300 psi, with the monomer acting as a solvent.

Novomer is talking to other toll manufacturers for larger-scale production runs, and is positioning its polymer technology to compete with conventional petroleum-based materials for applications such as flexible, rigid and microcellular packaging foams, thermoplastics, polyurethane adhesives and sealants, and coating resins for food-and-beverage cans.

CO_2-derived polyols are also being developed at Bayer MaterialScience AG (BMS; Leverkusen, Germany; www.bayermaterialscience.com), as part of the three-year Dream Production project, launched in 2010 with funding from the BMBF, and with partners RWE AG (Essen; www.rwe.com), RWTH Aachen University (www.rwth-aachen.de) and the CAT Catalytic Center (a research facility jointly run by the university and Bayer). A new zinc-based catalyst was developed as part of a forerunner project, Dream Reactions, to enable the efficient reaction of CO_2.

* A longer version of this article, as well as a table of more R&D projects, can be found online at www.che.com

Since the beginning of 2011, the company has been running its Dream Production Miniplant (Figure 1), which is now operating continuously and producing sample amounts (kilograms) for internal testing of the new material, says project leader Christoph Gürtler. The miniplant uses CO_2 that has been captured from the fluegas of a lignite-fired power plant operated by RWE in nearby Cologne.

BMS is now testing the polymers for potential applications. By mixing the CO_2-based polyether polycarbonate polyol with isocyanates, the company is producing samples of polyurethane foam for testing. Initial results show that the material containing CO_2 match those made the conventional way. If the new process continues to produce good results, Bayer intends to start industrial production of polyols with CO_2 from 2015.

Meanwhile, a lifecycle analysis (LCA) has been performed by RWTH Aachen University, and the results were reported last month at the International Conference on CO_2 Utilization (June 23–27; Alexandria, Va). The LCA analysis shows that the new materials do have a better carbon footprint than those made by conventional methods. "This is mainly due to the savings of fossil materials and replacing them by CO_2, says Gürtler.

Another "dream" reaction is the direct synthesis of acrylate from CO_2 and alkenes, says Michael Limbach, a chemist working at the Synthesis and Homogeneous Catalyst Dept. of BASF SE (Ludwigshafen; www.basf.com) and the Catalyst Research Laboratory of the University of Heidelberg (CaRLa; both Germany; www.carla-hd.com). Metal-catalyzed oxidative coupling of CO_2 with alkenes or alkynes is one of the most attractive routes to acrylates, but finding a suitable catalyst has eluded researchers for over 30 years, he says.

Until now. Last year, Limbach and his colleagues from BASF, CaRLa, and hte AG (Heidelberg; www.hte-company.com) reported the first synthesis of sodium acrylate from CO_2, ethylene and a base. The group developed a homogeneous organometallic catalyst based on nickel as part of the three-year, €2.2-million ACER project funded by BMBF, with BASF and hte adding an additional €1.7-million for the next few years. Sodium acrylate is a key ingredient for high-performance polymers, such as superabsorbent polymers used in diapers. The project aims to further develop the direct route to acrylates as an economical alternative to current production methods, which use fossil-fuel-derived propylene or propane in a two-step oxidation process, says Limbach. He estimates the current global-market volume for acrylic acid at approximately 4 million ton/yr. Although CO_2 is a cheap source of carbon, a great deal of expensive energy is needed for thermodynamic reasons, to make it usable. Production processes would therefore only truly consume CO_2 if this energy were generated "CO_2-neutrally," he says.

Fermentation methods

A demonstration plant for the production of acetic acid from the CO_2 in industrial offgases will be built at an operating plant of Petronas (Kuala Lumpur; www.petronas.com.my), Malaysia's national oil company, under an agreement with LanzaTech (Roselle, Ill.; www.lanzatech.com), developer of the process. Scheduled for startup in late 2013, the plant will be similar in size to a demonstration unit for a LanzaTech process that produces ethanol and 2,3 butanediol (2,3-BD) from the CO in offgases, says Mike Schultz, the company's vice-president of engineering. That plant started up last April at a Bao Steel (Shanghai) steel mill and produces 100,000 gal/yr (300 ton/yr) of ethanol (see *Chem. Eng.*, December 2010, p. 12).

The CO_2 process is similar to the CO technology in that it uses fermentation media containing naturally occurring bacteria that have been optimized to obtain a product (acetic acid in the case of CO_2). Raw offgases are sparged into the solution, and the CO_2 reacts with H_2 at 35–40°C to yield acetic acid, plus water. The rest of the components in the gases are inert and pass through the reactor.

Schultz says that, unlike CO, CO_2 is readily soluble in water, which makes the CO_2 process more effective. LanzaTech plans to recover the acid from the solution by counter-current solvent extraction (the CO process uses distillation to obtain ethanol). He notes that CO_2 is present in the offgases from many industrial processes and can account for as much as 50–60% of raw natural gas. H_2 for the process can be provided from various low-value sources, such as coke oven gas, hydrogen plant offgas, and refinery fuel gas.

Meanwhile, biotechnology is also being tapped as a method for making acetone, a widely used solvent that is also a key ingredient for making methyl methacrylate, isophorone and bisphenol A. Today, acetone is produced from fossil-based resources, reacting propylene and benzene into acetone and phenol. The goal of the BMBF-funded COOPAF project (CO_2-based acetone fermentation) is to develop a laboratory-scale, gas-fermentation process in which bacteria produce acetone directly from CO_2 and H_2. Natural acetogenic bacteria strains normally metabolize CO_2 and H_2 into ethanol and acetate. In cooperation with universities of Ulm and Rostock, metabolic engineered acetogenic bacteria strains that are able to produce acetone using CO_2 are being developed. In contrast to other R&D efforts, this project uses only CO_2 as the carbon source, says Jörg-Joachim Nitz, group leader, reactor technology, at Evonik Industries AG's (Essen, Germany: www.evonik.com) Coatings and Additives — BL Crosslinkers business unit in Marl, Germany.

Already the group has confirmed that it is able to produce acetone from CO_2 and H_2.

One advantage of this biotechnological gas-fermentation approach is that purified gases are not required as raw materials. "We can use CO_2- and H_2-rich waste gas streams," says Nitz, such as synthesis gas (syngas) from biomass, and offgases from steel processing.

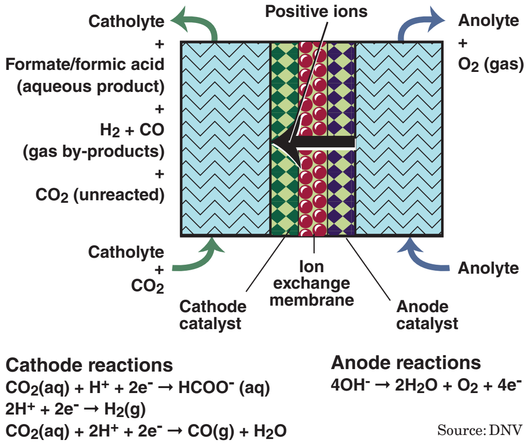


FIGURE 2. Electrochemistry is one way to reduce CO_2 into chemicals. The process shown here makes formate or formic acid, depending on the pH

Electrochemistry

Over the last four years, Det Norske Veritas (DNV; Oslo, Norway; www.dnv.com) has been developing its electrochemical process (ECFORM; Electrochemical Reduction of CO_2 to Formate) for making formic acid from CO_2. In the process (Figure 2), dissolved CO_2 is electrochemically reduced at the cathode into formate ions (along with small amounts of H_2 and CO) by a two-step, catalytic reaction, explains Edward Rode, principle researcher at DNV's Research and Innovation Group in Columbus, Ohio. At the anode, hydroxide ions are oxidized into O_2.

DNV has developed a highly selective cathode catalyst, based on tin or tin alloys, and a mixed-metal-oxides anode catalyst, which combine to reduce the total cell voltage by almost 1 V compared to other electrochemical routes. The electrochemical cell reactor has also been designed to reduce the resistive losses by another 2 V. As a result, the total cell voltage is decreased by about 60%, says Rode. The lifetime of the cathode catalyst has also been increased by at least 20 times over literature values, he says.

The ECFORM process has been tested in a semi-pilot-sized reactor with a superficial area of 600 cm^2, which is capable of reducing about 1 kg/d of CO_2. This unit was assembled into a solar-powered trailer to demonstrate the operation using completely renewable power. The reactor was modeled using gPROMS, a model-based flowsheet simulator from Process Systems Enterprises (PSE; London, U.K.; www.psenterprise.com). The model developed by DNV is also being used for scaleup assessment, says Rode. The next step will be a demonstration unit for converting 1-ton/d of CO_2, which Rode estimates will emerge in the next couple of years. Once developed at that scale, the process will be easy to move to commercial production scale by simply increasing the number of cells, he says.

Meanwhile, Dioxide Materials (Champaign, Ill.; www.dioxidematerials.com) is working on two aspects of CO_2 electrochemical conversion to fuels and chemicals: lowering the energy requirement for the primary conversion of CO_2 into CO or HCOOH and O_2; and expanding the market for the subsequent products to large-volume chemicals. One of the main thrusts

CONFERENCE NOTE:

For the latest on CO_2 utilization, readers may consider attending the 2nd Conference on CO_2 as Feedstock for Chemistry and Polymers, which takes place October 7–9 at the Haus der Technik, in Essen, Germany. Organized by nova-institut GmbH (Hürth, Germany; www.nova-institut.de), the event is expected to draw more than 300 participants from leading industrial and academic players in CO_2 utilization. ❑

is the use of bifunctional catalysts to lower the voltage needed to convert CO_2 to CO or HCOOH. Bifunctional catalysts are quite well known in industry, but they usually involve two different metals or a metal and a metal oxide. Dioxide Materials' advance was to develop novel bifunctional catalysts that combined a metal and an organic species (ionic liquids) to lower the overpotential for the reaction (that is, reducing the energy barrier for the formation of the CO_2^- intermediate).

Dioxide Materials' technology creates a new reaction pathway for the reaction, that does not require the high-energy intermediate so the wasted energy is much less. Research (published in *Science*) showed that CO_2 can be converted to CO and O_2 at 80% energy efficiency and 98% selectivity.

The initial work was done in a 1-cm^2 cell, but Dioxide Materials recently won a $5 million DOE Advanced Research Projects Agency (ARPA-E) award and is collaborating on the project with 3M (St. Paul, Minn.; www.3m.com), a sub-recipient of the ARPA-E award, and is currently evaluating the technology. Since the ARPA-E funded work started in February 2013, the team has already increased the CO output of the cell by three orders of magnitude (from microliters per minute to milliliters per minute). The final goal of the ARPA-E project is to increase the output to liters per minute, in a design that is scalable to the industrial (thousands of tons per day) scale.

Meanwhile, the BMBF-funded Sunfire project was started in May 2012 with the aim to produce Fischer-Tropsch (F-T) liquids from CO_2 and H_2O using renewable energy. The three-year project is lead by Sunfire GmbH (Dresden, Germany; www.sunfire.de), with seven partners from German research institutes and companies. The idea is to produce syngas by the reverse water-gas shift (RWGS) reaction ($CO_2 + H_2 \longrightarrow H_2O + CO$) using H_2 generated by high-temperature steam electrolysis. The syngas is then converted to liquids (gasoline, diesel, kerosene, methanol) and methane via F-T synthesis.

What makes the project unique is the use of a 10-MW prototype, solid-oxide fuel cell (SOFC) electrolyzer operating under pressure. Using electricity generated from renewable sources (solar or wind power), and by utilizing steam generated from the downstream RWGS and F-T reactions, the HT electrolyzer has an efficiency of over 90%, according to Sunfire. An integrated 159-L/d test facility will be constructed and used for validating the process under realistic operating conditions. ■

Gerald Ondrey

Newsfront

COOLING-TOWER WATER: A HYBRID PROBLEM CALLS FOR A HYBRID SOLUTION

In addition to the usual woes, new issues are creating a situation that calls for a hybrid approach to water treatment

BWA Water Additives

FIGURE 1. Processors are faced with the traditional cooling-tower water-treatment issues, as well as new problems related to water scarcity and intake and discharge restrictions, which require a new approach to water-treatment programs

BWA Water Additives

FIGURE 2. Here, BWA scientists are developing biodegradable, high-performance antiscalants for water treatment

Scaling, fouling and corrosion have long been the enemy of cooling-tower water. While these issues still present significant water-treatment hurdles, today's processors are also dealing with "impaired" water streams and increasing restrictions affecting intake and discharge water, among other challenges. This one-two punch has necessitated a hybrid approach — one that includes both advanced chemistries and modern, automated equipment — to cooling-tower water treatment (Figure 1).

Classic treatment objectives

Cooling-tower water treatment is an integral part of operations for processors because productivity and product quality can be adversely affected by scale, corrosion, fouling and microbiological contamination. These water-treatment problems can be very costly when they lead to the loss of heat transfer in the cooling tower, equipment failure, and health and safety concerns, according to Narasimha Rao, vice president, R&D and Automation, with Nalco Co. (Naperville, Ill.; www.nalco.com).

For this reason, delicately balanced chemistries are used to prevent scale, fouling and corrosion in cooling tower water. "A good water treatment company will create a tailored program to help processors tackle the particular issues that apply to the local stream of make-up water," says Tom Falsey, senior vice president of corporate sales with C.C.I. Chemical Corp. (Vernon, Calif.; www.ccichemical.com). "Every program will differ because make-up water will differ based on where it comes from, the region in which the facility is located, and factors such as the alkalinity, hardness, and other characteristics of the water."

Usually, a robust treatment program will include a balanced chemistry containing one or more biocides, algaecides, biodispersants, corrosion and scale inhibitors, anti-scalants, and cleaners.

Today's treatment objectives

As if finding the proper chemistry balance were not tricky enough, a recent set of water-related issues complicate matters further. The scarcity of water in many places and the tightening of discharge permits are among some of the reasons processors need to optimize water use. Additional factors include the anticipated U.S. Environmental Protection Agency (EPA; Washington, D.C.) regulation surrounding cooling-tower intake water. Section 316(b) of the Clean Water Act will require that the location, design, construction and capacity of cooling-water intake structures reflect the best technology available for minimizing adverse environmental impact. "These anticipated regulations will force processors to either install equipment that will reduce fish entrainment at the intake or draw their cooling tower water from elsewhere," says Kaveh Someah, global director, oil-and-gas and refining and petrochemical industries with Ovivo USA (Salt Lake City, Utah; www.ovivowater.com).

"For these and other reasons, it's not unusual to see a cooling system with multiple sources of water blended together in varying ratios being used as cooling tower makeup water," says Eric Thungstrom, global cooling product manager, water and process technologies, with GE Power & Water (Trevose, Pa.; www.ge-energy.com). "This can lead to variable water quality, and if a treatment program is designed around a projected water quality, but if that water quality is more variable than what was projected, it may put additional stress on the treatment program and cause performance issues, such as corrosion or scaling."

CLEANING BEYOND THE COOLING TOWER

With so many processors using reclaimed water, the challenge becomes how to treat a reclaimed water source and turn it into useable water, notes Kaveh Someah, global director for the oil and gas industries with Ovivo USA. "Reclaimed water is often high in nutrients, which can cause microfouling that leads to slime on the heat exchangers. High salt, phosphate and ammonia levels may coat metals and create cracking in equipment, so proper treatments must be found."

Traditional processes for handling these issues might include combinations of biological, physical and chemical treatments. For example, multimedia filters might be used to remove total suspended solids and floating solids. Then, nutrients might be removed via a clarifier or other biological treatment, which may be followed by reverse osmosis to remove dissolved solids from the stream. All this would be done prior to running the water through the cooling system.

"Although these methods combined with chemistry in the cooling tower may prevent scale from forming in the cooling tower, scale will still eventually form. The chemicals just delay where the scaling occurs," says Someah. "As the water leaves the cooling tower and heads into the process equipment where the temperature rises, the salt precipitates out, which can lead to scaling. However, an online cleaning system can be installed inside the heat exchanger and condensers to prevent and remove scale and fouling."

To assist, Ovivo offers the Automatic Tube Cleaning System, which prevents scale deposits and microfouling 24 hours a day, increasing reliability, performance, plant output and service life of the equipment. The system injects elastomer rubber balls that are slightly larger than the tube diameter into the water supply line so that the flow of cooling water forces them through the condenser tubes. The balls wipe the tubes clean of deposits including silt, scale, and biological fouling. A strainer section in the cooling water outlet extracts the balls and a centrifugal pump moves them into a collector section where they are ready for the next cycle. Balls can be recirculated continuously or intermittently to suit the plant. ❑

Often, processors use a blend of waters, such as reverse osmosis (RO) reject water, well water, river water with suspended solids, blowdown water from the boiler or cooling-tower and municipal wastewater. In addition, many facilities are being forced to achieve zero liquid discharge, so the water sources may be highly concentrated. This mixed, impaired water stream can create a host of challenges, says Thungstrom.

Adding to the water-source-related issues are tightening discharge issues. "Processors now have to deal with meeting regulations that affect effluent limitations, such as requirements that demand lower discharge limits on phosphorus, nitrogen, and BOD/COD (biochemical oxygen demand and chemical oxygen demand)," says Nozi Hamidi, vice president of marketing with BWA Water Additives (Atlanta, Ga.; www.wateradditives.com).

The cost of complying with such limitations, combined with a global awareness of environmentally re-

FOOD PROCESSOR USES TECHNOLOGY TO CONTROL COOLING COSTS AND WHITE RUST PROBLEM

For one food processor, make-up water hardness was so low, alkalinity so high, and variation in water chemistry so frequent that white rust — corrosion of galvanized steel — resulted in capital cost expenditures of $750,000 to replace failed cooling towers.

White rust caused premature failure of galvanized-steel components. A white gelatinous or waxy deposit often identifies white-rust corrosion. This deposit, a zinc-rich oxide, is porous and generally non-protective. High alkalinity, high pH and low hardness cause the problem. All of these conditions existed at this facility and were aggravated by variations in water chemistry that made control problematic.

The cooling-system make-up water contained 4–6 parts per million (ppm) of calcium hardness, necessitating high-cycle operation to obtain the minimum 50 ppm calcium hardness recommended by the Cooling Tower Institute (CTI; Houston; www.cti.org) to prevent white rust. Acid feed was also required to bring the alkalinity within CTI guidelines.

New evaporative condensers were installed in November 2003, and a very small amount of white rust became apparent upon inspection months later. Concerned that this condition would result in further damage to the cooling towers, the plant engineering staff installed Nalco's 3D Trasar system in January 2004. The technology measures key parameters related to system stress. When upsets occur, 3D Trasar technology takes timely, appropriate, corrective action. It then communicates with system users, informing them of what happened, as well as the actions taken to compensate.

High-cycle operation required acid feed in order to reduce alkalinity. If the acid-feed system failed, the tower pH would rise. At higher pH, conditions would be right for white rust formation. Timely attention to any failure of the acid-feed system was critical to preventing this operational problem. The automated technology provided alarm notification via cell phone, text message, email, or digital pager, ensuring the right people knew about any problem immediately and could take corrective action.

Weekly inspections are conducted on the cooling tower and results since installation of the technology have been excellent. The automation program has been able to better control the system water chemistry, white rust has been abated and an expected $45,000 per year in cost savings has been realized. An important key to the success of the program is the alarm notification feature. It contacts Nalco via cell phone and communicates specific problems so that immediate response can occur. This has helped keep the program in compliance more than 99% of the time.

No scale or other mild steel corrosion problems have been observed and cost savings have come from longer expected evaporative condenser life ($25,000 per year), reduced cooling-water sewer costs ($10,000 per year), reduced treatment chemical costs ($8,000 per year) and labor savings from reduced testing ($2,500 per year). ❑

GE Power & Water

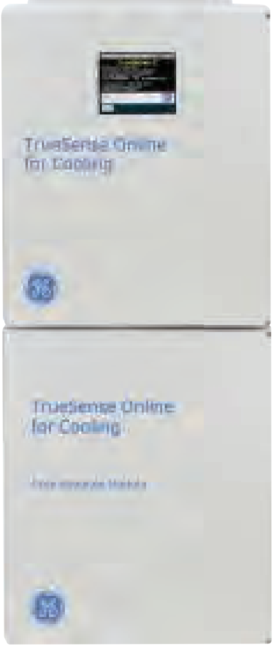


FIGURE 3. TrueSense Online for Cooling is an integrated platform that directly measures and controls applied chemistries that are critical for managing cooling-water efficiency and preserving key assets in industrial cooling systems

sponsible use of chemicals, has caused many processors to pursue controlling these factors within the plant rather than passing them on to the local water treatment facility, which might be treatment limited or invoke surcharges for wastewaters with high levels of certain constituents, says Hamidi. "This has led to processors targeting reduction or elimination of any contributors to the plant effluent that will tip the limits for phosphorus, nitrogen and other constituents," she says. "Often, typical phosphonate-based cooling water chemistries will be the largest contributor of phosphorus and nitrogen, and therefore will spur substitution to 'P-free and N-free' cooling-water treatment chemistries."

Solving combined challenges

Between handling tough-to-treat water sources and stricter discharge limits, water treatment experts say a hybrid water-treatment approach is needed. New and advanced chemistries designed to meet the discharge limits should be combined with technologies that can help consistently, accurately and automatically dose the chemicals and keep track of making sure nothing is off balance.

New and advanced chemistries might include something like BWA Water Additives' Belclene 810, which is a biodegradable "PMA," or polymaleic acid, that can be used in cooling-water treatment programs where the processor requires P-free, N-free or metals-free formulations and also wants to achieve very high cycles of concentration within the cooling tower to save water. This chemistry is considered "environmentally acceptable" and is both a threshold and a crystal growth inhibitor, which makes it better at scale inhibition than phosphonates that are typically just threshold inhibitors, while meeting P-free and N-free treatment objectives (Figure 2).

Nalco

FIGURE 4. A technician looks inside a 3D Trasar Controller, which helps maintain control over critical cooling assets

For the processor who has RO membranes in their operations, BWA has also developed Flocon 885, a biodegradable, P-free and N-free antiscalant used to control organic deposits that can develop on RO membranes.

In addition to chemistries that meet modern discharge requirements, Thungstrom says processors also require more stable and effective chemistries. GE Power & Water offers GenGard 8000 for control of corrosion and deposits in open recirculating cooling systems. GenGard programs can be applied across the entire pH spectrum from neutral to alkaline and ensure results even under stressful conditions.

Nalco

FIGURE 5. This image shows the 3D Trasar technology set up on a cooling tower.

Nalco

FIGURE 6. Here, the 3D Trasar technology is set up for a cooling water skid

The technology includes a stress-tolerant polymer (STP), alkaline-enhanced chemistry (AEC) and halogen-resistant azole (HRA) in combination with phosphate-based steel corrosion inhibitors.

Even with advanced chemistries, chemicals alone are not enough, say the experts. "Likely the most important tool is one that can control the treatment program," says Thungstrom. "And, with all the possible variation in today's water streams, a sophisticated control system is often needed."

Simple control systems will take a single input and turn the chemical feed pump on and off accordingly. However, sophisticated monitoring can make adjustments to the chemicals and send alerts when additional actions need to be taken.

Among the sophisticated systems is GE's TrueSense Online (Figure 3) for Cooling. The integrated platform directly measures and controls applied chemistries that are critical for managing cooling water efficiency and preserving key assets in industrial cooling systems.

Nalco offers the 3D Trasar System (Figure 4–6), which uses real-time monitoring, patented control technology, stress-resistant chemistry and 24/7 information management capabilities to detect, determine and deliver improved scale, corrosion and microbiological performance in cooling systems. It is able to detect the upsets that precede scaling, corrosion and biofouling and then deliver the appropriate chemical response. The result is a balanced, efficient and safe cooling system that requires less maintenance, no over- or under-dosing of chemicals, lower operating costs, and maximum asset protection.

While cooling-tower water treatment may present more challenges than it did in the past, service providers are working hard to make sure their offerings help processors continue to go with the flow. ■

Joy LePree

BinMaster

FOCUS ON

Level Measurement

Vega Grieshaber KG

Krohne Messtechnik

Precision Digital

Reliable switching down to –196°C

The Vegaswing 66 vibrating level switch (photo) is said to be the first of a kind for extreme temperatures. Especially suitable for cryogenic liquids, the device switches reliably in process temperatures from –196 to 450°C, and operates at pressures from vacuum to 160 bars. The level switch offers increased protection and safety for gas-liquefaction plants and liquefied gas tanks used for processing, transporting or storing liquefied natural gas (LNG) or liquid nitrogen. The device has standard approval for explosion protection according to ATEX and FM, as well as for use on ships and offshore platforms. — *Vega Grieshaber KG, Schiltach, Germany*
www.vega.com

Corrosive environments are not a problem for these meters

Launched in February, the Optiwave 5200 C/F is a new 10 GHz FMCW (frequency modulated, continuous wave) radar level meter (photo) for liquid applications up to 300-m measuring range. The two-wire, loop-powered device measures level and volume in storage or process tanks with process temperatures up to 250°C and pressures up to 40 bars. The unit has been designed and developed for use in SIL-2 safety-related systems according to IEC 61508. The polypropylene (PP) and polytetrafluoroethylene (PTFE) Wave Horn antennas are process sealed by their antenna material instead of a traditional O-ring seal construction. These gasket-free antennas are therefore suited for extreme corrosive environments, says the company. The new meter is compliant with requirements such as SIL and Namur recommendations NE 107, 21, 43 and 53, and offers a 4–20-mA HART communication with dedicated PACTware DTMs. — *Krohne Messtechnik GmbH, Duisburg, Germany*
www.krohne.com

This explosion-proof meter displays level and volume

The PD6801 ProtEX F&I Level Meter (photo) is an easy-to-read, explosion-proof meter designed for safe or hazardous environments, such as oil wells or chemical storage. The 4–20-mA loop-powered input displays level in feet and inches; a second line shows volume, percent or a custom label. The meter also features a 20-segment tank-level indicator that displays the height. The meter is optimized for wide-angle viewing of about 80 deg. The meter has FM, ATEX, CSA and IEC Ex approvals, and is housed in a cast-aluminum NEMA 4X enclosure. — *Precision Digital Corp., Hollister, Pa.*
www.predig.com

This capacitance probe is flexible for tight fits

This bendable capacitance probe (photo) is designed to fit into tight spaces or in vessels where obstructions prevent the installation of a straight probe. The probe can be bent to avoid obstructions in a vessel while still allowing adequate probe surface area to confirm the presence or absence of material. Mounted on the side of the bin, the bendable probe can be used in a wide range of solid materials or slurries. These capacitance probes work at 6 kHz — far below the radio-frequency (RF) level of 9 kHz — and will not interfere with two-way radios or other equipment operating in the radio spectrum, says the company. Standard probes feature a triple-

American Sensor Technologies

Omega Engineering

threaded, screw-off cover that allows easy access to internal components and an FDA-recognized powder coat finish. — *BinMaster, Lincoln, Neb.*
www.binmaster.com

Submersible transmitters that measure depth or level

The PX709GW Series submersible level/depth transducers and transmitters (photo) are designed to make precision level or depth measurements in fresh water or liquids that are compatible with 316 stainless steel. The standard device has an accuracy of 0.20%, and optional high-accuracy models are available with 0.8% accuracy. They are available with lightning and surge protection, and have outputs of 4–20 mA, 0–5 V or 0–10 V. — *Omega Engineering, Inc., Stamford, Conn.*
www.omega.com

Conduit fittings protect this level sensor's cables

Since last August, this company has supplied its liquid level sensors (photo) with ½-in. NPT male conduit fittings before the cable interface. This is beneficial if the sensor is going to be exposed to a liquid not compatible with the material. It also adds stability in turbulent tanks. For installations where the level sensor is threaded into a tank, users prefer to install conduit to protect the cable from the work environment. AST 4500, 4510 and 4520 level sensors are Class I Div. 1 intrinsically safe, Group C and D when installed with a barrier as well as ABS (American Bureau of Shipping) certified. Pressure ranges are available as low as 0–1 psi (27.68 in. water column) — *American Sensor Technologies, Inc., Mt. Olive, N.J.*
www.astsensors.com

Monitoring tanks remotely through the cloud

Tank Cloud Remote Monitoring (photo) is a cost-effective remote tank-level-monitoring system that enables users to monitor facilities and processes from anywhere with an Internet connection, 24 hours per day, 7 days per week. Using the company's proprietary remote level sensors and modules, or any sensor with a 4–20-mA output, Tank Cloud users can remotely monitor level, pressure, temperature, flow, pH and other process variables through an easy-to-use online interface. Sensors and input modules connect to the user's network via an Ethernet cable and transmit data via the user's internet connection, whether landline, cellular, radio or satellite. On Tank Cloud remote monitoring Web portal, operators and managers have ready access to realtime and historical data, and can manage various alarms and set permission levels for various personnel. The system notifies all relevant workers of alarms via email and text messaging. — *Automation Products Group, Inc., Logan, Utah*
www.apgsensors.com

Control the level in hazardous areas

The Fisher L2e level controller (photo, p. 26) uses a rugged force-balanced displacer sensor to detect the level of a single liquid or the interface of two liquids. The controller's new knife-edge sensing design combines with aerospace-quality switch technology to provide rugged, reliable and accurate level control, says the company. The L2e zero and span adjustments enable tuning for a wide variety of level-loop applications. Additionally, the controller is certified for use in hazardous areas and is NACE-compliant for "sour" service. By scanning the QR code on the inside cover of the L2e, instrument technicians have access to 24/7 field support for setup, calibration and loop tuning. — *Emerson Process Management, Marshalltown, Iowa*
www.emersonprocess.com

This switch has a SIL2 rating and many approvals

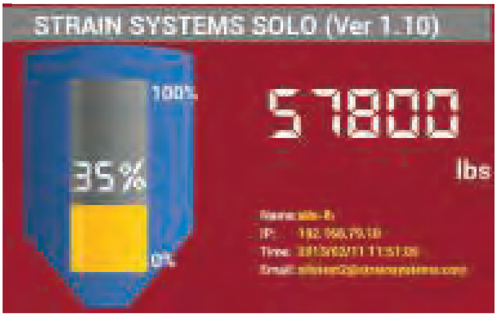
The FLT93 Series FlexSwitch (photo, p. 26) is a precision flow/level/temperature switch for use in liquid, air, gas or interface service. Suitable for oil-and-gas upstream production or downstream refining, storage and distribution, the FLT93 Series FlexSwitch provides dependable relief-valve monitoring and flare-gas flow or leakage detection. The device is said to be the most advanced heavy-duty thermal-dispersion technology flow and level switch available. SIL2-rated for ultra reliability, the device also has Ex agency approvals for the entire instrument, including FM, FMc, ATEX and IECEx. — *Fluid Components International, LLC, San Marcos, Calif.*
www.fluidcomponents.com

This weighing system also has a level-measurement feature

Because raw materials are purchased,

Emerson Process Management

Fluid Components International



Strain Systems

consumed and reconciled in terms of weight, this company's products are designed to provide direct weight measurement for bulk materials stored in silos. However, because many operators use level devices and then calculate weight from data, which may be uncertain, this company now offers a level measurement feature on its Solo product line (photo), which combines the patented StrainCell sensor with intelligent electronics. As a result, users can see silo weight and level on the display at the same time. The technology has a proven accuracy of 1% of full scale for steel-legged silos and within 3% of full scale for steel-skirted silos. — *Strain Systems Inc., Bellevue, Wash.*
www.strainsystems.com

This GWR transmitter has three times better signal-to-noise
The Eclipse Model 706 guided-wave-radar (GWR) transmitter is said to be a best-in-class level-control solution. Designed to provide outstanding accuracy, reliability and safety, the latest-generation features include enhanced signal performance. The GWR circuitry achieves both a higher transmit-pulse amplitude and improved receiver sensitivity, which leads to a signal-to-noise ratio that is three times higher than competitive GWR devices, says the company. Unlike other GWR transmitters that use algorithms to infer level readings in top-of-the-probe dead zones, the Eclipse 706 measures true level to within specification all the way up to the process flange. The new transmitter also features advanced diagnostics, with LCD diagnostics conveyed in realtime waveform and trend data. — *Magnetrol International, Inc., Downers Grove, Ill.*
www.magnetrol.com

A multiparameter transmitter now includes batch controlling
In March, this company introduced the second generation Signet 9900 Transmitter, which includes a Batch Controller option along with the features of the original version. This new transmitter supports multiple parameters that include level, flow, pH/ORP, temperature, pressure and more — and now also for batch systems. Users can convert their second-generation 9900 transmitter to a batch controller system by simply plugging in the new Batch Module and Relay Module, thereby maintaining the product's original intent of consolidating multiple platforms into one while increasing their service level and reducing inventory, says the company. — *GF Piping Systems, Tustin, Calif.*
www.gfpiping.com

Measurements from remote sites right to your desktop
AutoLog GSM Wireless Probe is a new compact and robust device that performs liquid level measurements and sends the data to your desktop. The system uses widely spread GSM/GPRS networks as communication. Operators can access data from any computer's Web browser, anywhere and at any time. The system does not require a separate control room, server PC or special maintenance staff, so investment and operating costs are low. Data logging and sending is possible at programmable intervals. Measurements, alarms, trends and reports from objects can be shared by all users. — *FF-Automation Oy, Vantaa, Finland*
www.ff-automation.com

An imersion sensor that measures interfaces
The Turbimax CUS71D ultrasonic immersion sensor is used for interface measurements in processes where suspensions are separated into their liquid and solid components by sedimentation. The device can continuously monitor the separation and transition zones of the clarification and settling phases. The sensor uses a piezoelectric crystal to generate ultrasound, and measures the time required for the signal to reach solid particles in the separation zone, and then return to the receiver. The sensor is used with the company's M CM44x multi-parameter/multiple-sensor transmitters — one sensor for the CM442, and up to four can be connected to a CM444 or CM448 transmitter. — *Endress+Hauser, Inc., Greenwood, Ind.*
www.us.endress.com

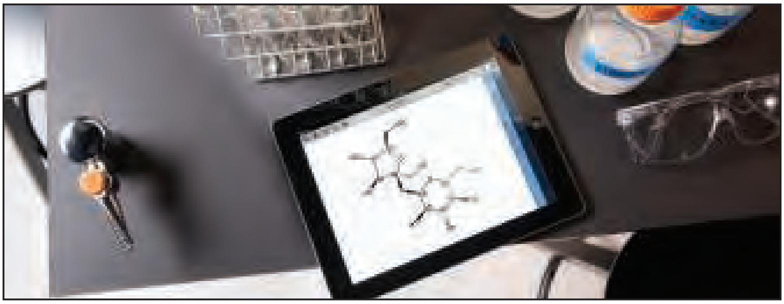
Level control is simplified with non-steady-state tuning
This company's software includes non-steady-state (NSS) modeling features for integrating control loops. These tools are said to provide fast, simple modeling and tuning of level controls. Unlike temperature, pressure and flow, level controls have different dynamics, and these new tools make it simple to tune level controls, even while the level is moving, says the company. NSS tuning integrates seamlessly with the company's PlantTriage and PID Loop Optimizer software. These tools also provide capabilities for both tight control and surge-tank scenarios. NSS modeling is included with PlantTriage Version 11 and higher, and with PID Loop Optimizer Version 21 and higher. — *ExperTune Inc., Hartland, Wisc.*
www.expertune.com ■

Gerald Ondrey

JULY
New Products

Chromalox

PAC


PerkinElmer

This compact digital heat-trace controller offers versatility

The new ITC Series intelliTRACE controller (photo) is designed for line- or ambient-sensing heat trace applications in hazardous (Class I, Division 2) or non-hazardous areas. Available in single- and dual-circuit models, the ITC features a high-resolution display and may be used in either freeze-protection or process-control temperature applications monitoring all process variables both locally and remotely. The ITC is a microprocessor-based system with solid-state-relay power control, selectable soft-start program, current load, dual resistance-temperature-detectors (RTD) sensor input for each circuit, and ground fault equipment-protection monitoring. There are three user-selectable control modes available on the ITC: manual, off or auto. The ITC's compact enclosure facilitates electrical connections for the heating cable, the a.c. power, and the RTD sensors. This controller may be used with constant wattage, mineral-insulated or self-regulating heat-trace cables. *— Chromalox, Inc., Pittsburgh, Pa.*
www.chromalox.com

This jet fuel analyzer enhances safety through automation

The Alcor JFTOT 230 Mark IV (JFTOT IV) is a new jet-fuel thermal oxidation analyzer (photo) designed for increased safety and simplicity. New safety measures in this compact model ensure minimal jet-fuel vapor-exposure to personnel and the environment through the sample and waste containers. The sliding test door also prevents exposure to the high-temperature heater-tube test section. The JFTOT IV simplifies operational capabilities through automation of tasks, such as priming the pump, monitoring sample flow and aerating the sample. The JFTOT IV is listed in Table 1 of ASTM D3241-13, "Standard Test Method for Thermal Oxidation Stability of Aviation Turbine Fuels," as an acceptable instrument model. *— The Petroleum Analyzer Company (PAC), L.P., Houston, Tex.*
www.paclp.com

Draw, view and share molecular structures in realtime

New ChemDraw and Chem3D apps for iPad tablets (photo) provide mobile access to robust molecular drawing and viewing tools for use in education, R&D and publishing. The apps feature the unique Flick-to-Share tool, which gives users the ability to rapidly share molecular structures across mobile devices, eliminating the need for emails and cloud storage services. Chem3D is a molecular viewer app where scientists can explore structures in three dimensions by using the touchscreen to rotate, expand and contract models for a clearer display of spatial properties. Chem3D can display 3-D models of proteins, DNA, crystals and assemblies in many formats, such as ball-and-stick, wireframe, space-filling and cartoon. *— PerkinElmer, Inc., Waltham, Mass.*
www.perkinelmer.com

Use this vertical blender for low-shear mixing or vacuum drying

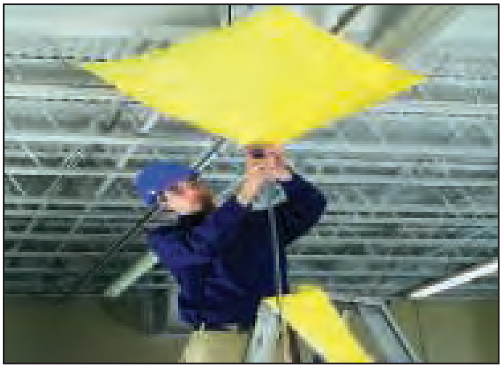
This company's vertical blenders (photo, p. 28) are used for low-shear blending and vacuum drying. Compared to other blender varieties, vertical blenders are gentler, allowing for mixing of powders, pellets, granules and fibers in delicate and abrasive conditions. In vacuum drying operation, the blenders can accommodate slurries, wet cakes, pastes and flowable solids. Requiring only low heat to drive off moisture or solvents, vacuum drying in a vertical blender dries heat-sensitive materials without risk of thermal degradation, while also consuming less energy. The blender features a mechanical arm that rotates an auger around the conical vessel. The auger turns on its own axis. Spray nozzles may be installed for liquid addition and coating purposes. — *Charles Ross & Son Co., Hauppauge, N.Y.*
www.mixers.com

Avoid cross-contamination with this lubrication system

This Lubrication Storage and Dispensing System (photo, p. 28) consists of two 65-gal containers and one 130-gal container. Features to the customizable system include three-way product diverter valve assemblies, individual pumping systems, and

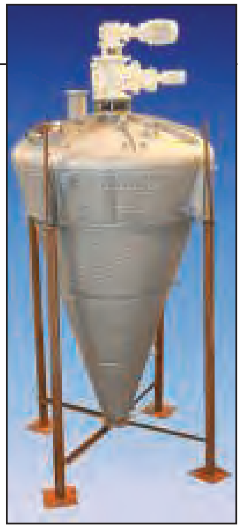
Note: For more information, circle the 3-digit number on p. 56, or use the website designation.

New Products



New Pig

The IFH Group



Charles Ross & Son

tems, and 10-µm filters. Products are pumped in and out of the system via individual pumping systems, which prevent cross-contamination. The three-way diverter valves, in combination with the individual pumping systems and filters, allow product to be pumped through the filters into the containers, and then pulled back out of the containers through the filters with the transfer units. Product can also be pulled from the containers, cycled through the filters and sent back into the containers. For further protection against product spills, an optional spill-containment system is available. — *The IFH Group, Inc., Rock Falls, Ill.*
www.ifhgroup.com

This process monitor offers several display options

Designed for monitoring flowrate, total, limit, batch and ratio measurements, the MX 9000 Process Monitor can also report pressure, temperature, and information from other devices with analog signals that can be monitored. The MX 9000 comes installed with new plug-in option boards, backlit display with color-coded indicator and a USB port. The backlit display's red, green and blue color-coding also allows for alarm indication visibility. The display board facilitates multiple display modes and variable-programming options with its graphic LCD module and four push-buttons. The board can be customized for special projects or applications and an optionboard slot allows for features such as relay outputs, networking, voltage/current inputs, and frequency outputs. — *AW-Lake Company, Franksville, Wisc.*
www.aw-lake.com

Spirax Sarco

Oven Industries

Protect inventory and machinery with this leak diverter kit

The recently introduced Quick Deploy Leak Diverter Kit (photo) provides a fast response to roof and pipe leaks. It catches nuisance leaks by diverting them to a floor drain or collection container. Complete with a discharge hose and fittings, the Quick Deploy can be installed by simply hooking the handle over a pipe or ceiling truss. Pinched corners help funnel liquid toward the center of the diverter for better drainage. The included PVC drain hose channels the captured liquid to a collection container, drain or other containment device. The Quick Deploy is vinyl-coated for strength and flexibility and resists punctures, ultraviolet light and mildew. — *New Pig Corp., Tipton, Pa.*
www.newpig.com

This flow transmitter provides high signal strength

The EFT10 Electromagnetic Flow Transmitter (photo) measures all types of conductive liquids, including those used for applications in mining, slurries, waste, and low-conductivity media. The EFT10 provides bidirectional flow signal and combines the pulse hybrid method of coil excitation with digital communications. Customizable with keyboard programming, the transmitter features a 10-year memory, batch control, and a scalable pulse-frequency output. Combining the EFT10 with this company's UniMag flow tube provides a useful option for measuring low-conductivity liquids due to its ultra-stable flow signal-to-media noise ratio. — *Spirax Sarco, Inc., Blythewood, S.C.*
www.spiraxsarco.com/us

This controller gives dual options for setting in the field

The very compact 5R1-1400 a.c. Temperature Controller (photo) can deliver up to 15 A of load current from a zero voltage switched, low-noise solid-state relay. Featuring temperature resolution of 0.1°C, the 5R1-1400 exhibits an ambient operating range of –20 to 70°C. The controller has options for integrated potentiometers (for set temperature and process-integral control) and PC-programmable logic (for set temperature and process-integral-derivative control). The set temperature range is determined by thermistor type. Accessories for the 5R1-1400 include temperature sensors, flange mount and a USB interface cable. — *Oven Industries, Inc., Mechanicsburg, Pa.*
www.ovenind.com ■

Mary Page Bailey

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Polymer-based Piping

Polymer-based piping systems offer a number of advantages, along with some limitations, compared to metallic and other non-polymeric pipe materials. The use of thermoplastic piping in the chemical process industries (CPI) must be carefully considered on a case-by-case basis because of the constraints introduced by various CPI applications. Polymers remain only a small (~10%) part of the global CPI piping market, but their technical potential may encourage wider use.

Polymer-based pipes can manage almost any chemical load up to temperatures of 100°C in the moderate pressure range (pressures less than 10 bars). There is a general trend toward more pressure-resistant and stiffer pipes.

Advantages of polymer piping	• Chemical resistance (defined by the polymer's chemical identity) • Cost-to-performance ratio • Low weight • Electrical and thermal insulating properties • Availability of parts • Versatile jointing
Limitations of polymer piping	• Comparatively high thermal expansion • Longterm creeping under mechanical load • Significant reduction in mechanical properties under increasing temperatures • Non-destructive monitoring of corrosion process is not sufficiently developed for plastics

Most projects in the CPI require at least one or more of the following constraints for piping:

- Considerable safety margins
- Sufficient chemical resistance
- Predictable or manageable corrosion
- Uniform corrosion behavior for all components in contact with the media
- Simple maintenance
- Attractive price-to-performance ratio
- High level of availability of the components
- Availability of field references
- Ease of installation

Although polymer-based piping systems have not reached the level of usage of metal-based piping in the CPI, there are a variety of industry segments where the specific advantages of polymer pipes have been understood systematically and successfully exploited. The global chlorine industry, basic-chemical synthesis, logistic partners for chemical media, surface technologies (for example, galvanizing and pickling), pulp-and-paper and power plants are the most important fields of application.

Some polymer-based piping vendors offer complete harmonized systems encompassing a wide range of dimensions and pressure ratings. Such systems cover integrated solutions of measurement and control units, as well as various valve systems.

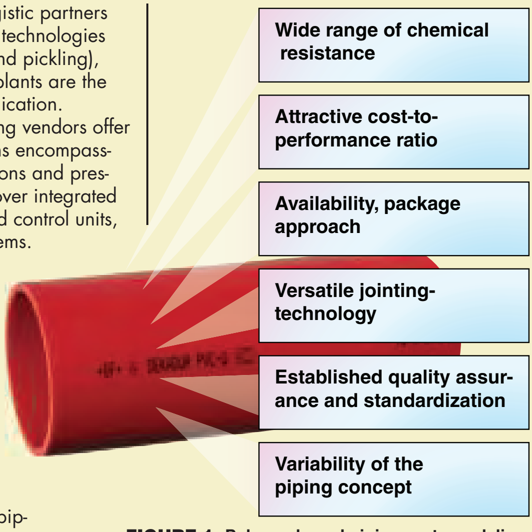


FIGURE 1. Polymer-based piping systems deliver many advantages, such as those listed here

Plastic pipe jointing

Thermal welding and solvent jointing are predominately used in the CPI for plastic pipes. The welding of polymer piping in the CPI can be divided into socket-, butt-, fusion- and rod-welding. Socket and butt-welding are used for pure thermoplastic piping. Fusion- and rod-welding are used for fiber-reinforced thermoplastic piping (dual laminates).

When solvent-based glues are used for cement jointing, various types are used — the respective formulations are fine-tuned to match the individual requirements defined by the polymer type and the field of application. As soon as the dimensions of fabrication tolerances of pipes and fittings exceed a certain limit, solvent-cement jointing becomes no longer practically feasible due to both the gaps that need to be "bridged" and the procedure of assembly (required forces, application of the cement and so on).

Corrosion and chemical attack

A substantial body of research and case studies has been built over time surrounding the corrosion of various polymer materials when in contact with different chemical media under different conditions. In terms of the integrity of plastic pipes, two types of interactions — permeation and direct attack — are most important.

Solvation or permeation involves gas, vapor or liquid molecules passing through the polymer, without chemical changes occurring to the polymer itself. However, physical properties may be affected. Permeation may not harm the polymer material, but can have application-related effects. In general, thermoplastic pipes should not be used where a permeating chemical surrounds the pipe and could compromise the purity of the fluid inside.

Direct chemical attack occurs when exposure to a substance causes a chemical alteration of polymer molecules by chain scission, crosslinking, oxidation or substitution reactions. Direct chemical attack may cause profound, irreversible changes that cannot be restored by removal of the chemical. Chemical attack frequently causes severe reduction of mechanical and physical properties, such as tensile strength, ductility, impact resistance and susceptibility to cracking from applied stress (stress cracking).

A number of factors can accelerate chemical attack. Three significant ones are: concentration, temperature and stress. Generally, the resistance of a particular plastic to a specific chemical decreases with increasing concentration. The resistance of a particular plastic to a specific chemical decreases with temperature increases, and generally decreases when applied stress is varied or cycled. Combinations of different chemicals should also be considered. ■

Thermoplastic polymer materials used for piping

Acrylonitrile-butadiene-styrene (ABS)
Chlorinated polyvinyl chloride (CPVC)
Polypropylene (PP)
Polyvinyl chloride (PVC)
Polyethylene (PE)
Polybutylene (PB)
Polyvinylidene fluoride (PVDF)
Cross-linked polyethylene (PEX)*
Polyamide 11 (PA11)
Polyketone (PK)

*crosslinks remove thermoplasticity

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A solution-based route to LLDPE

By Intratec Solutions

Polyethylene (PE) is the world's largest-volume commodity polymer. Along with high-density (HDPE) and low-density (LDPE) polyethylene, linear low-density polyethylene (LLDPE) is one of the three main types of PE. The global market for LLDPE is over 20 million metric tons per year, corresponding to about 30% of the total PE produced.

In LLDPE production, three major types of low-pressure technologies are used: slurry, solution and gas-phase processes.

The process

LLDPE is produced by copolymerization of ethylene with alpha-olefins using Ziegler-Natta catalysts. The most common co-monomers used in LLDPE production are 1-butene, 1-hexene and 1-octene.

Figure 1 illustrates the process for butene-based LLDPE production via a solution technology similar to Nova Chemicals' (Calgary, Alta.; www.novachem.com) solution-phase technology, known as SclairTech (Figure 2). The process shown is a swing process, which is also capable of producing different LLDPE and HDPE grades by utilizing other alpha-olefins as co-monomers.

The process can be divided into four main operation areas: purification and catalyst preparation; reaction; distillation; and finishing.

Purification and catalyst preparation. The cyclohexane solvent, ethylene and comonomers are sent to fixed-bed adsorption systems to remove water, oxygen and other polar impurities. The catalysts used in the process are based on mixtures of titanium and vanadium compounds, in conjunction with aluminum alkyls cocatalysts. These components are mixed with solvent and pumped to the polymerization reactor.

Reaction. Ethylene and 1-butene comonomer (in case of butene-based LLDPE) are dissolved in cyclohexane solvent and sent to the reaction step. The polymerization is carried out in a solution phase, at a temperature above the melting point of the resulting polymer. The reaction system consists of a tubular reactor and a continuous-stirred-tank reactor (CSTR). The low residence time of the reactors enables a high flexibility for grade transitions, as well as versatility for the production of resins with a wide range of densities, melt indexes and molecular weight distributions. The reactor output stream is fed into separator vessels, where unreacted ethylene and co-monomers, solvent and any other volatile matter are separated from the PE. The polymer is sent to the finishing section while the light stream moves to the distillation system.

Distillation. The distillation step comprises five distillation columns in charge of recovering the unreacted ethylene and co-monomers; recovering the solvent; purging impurities, such as oligomers (also called grease), catalyst and deactivators residues; and avoiding the buildup of inert components, such as isomers of the co-monomer.

Finishing. The resulting polymer from the reaction area is fed into an extruder, which is used to incorporate the required additives, and to pelletize the polymer. The product is then sent to the product blending and storage stage.

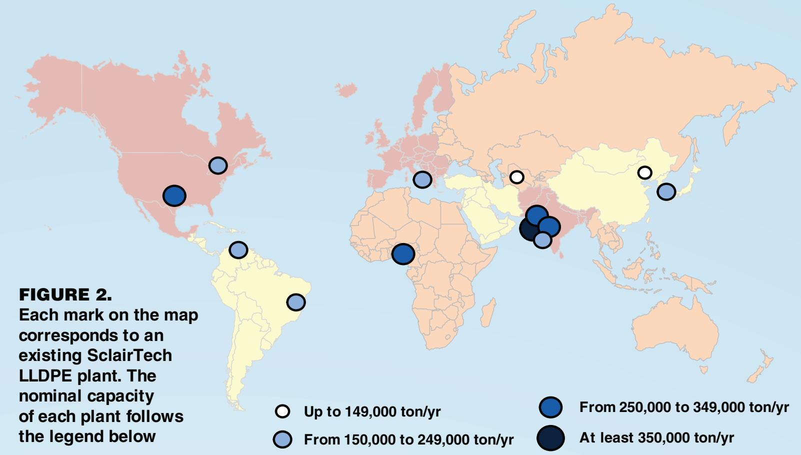

FIGURE 2. Each mark on the map corresponds to an existing SclairTech LLDPE plant. The nominal capacity of each plant follows the legend below

Economic performance

An economic evaluation of the solution-phase LLDPE process was conducted based on data from the fourth quarter of 2012. The following assumptions were taken into consideration:

- A 350,000 ton/yr unit erected on the U.S. Gulf Coast (the process equipment is represented in the simplified flowsheet)
- Storage of products is equal to 20 days of operation, and there is no storage for feedstock
- Outside battery limits (OSBL) units considered: steam boilers, cooling towers, propylene refrigeration system, heat-transfer fluid unit, control room and administrative buildings

The estimated capital investment (including total fixed investment, working capital and other capital expenses) to build the LLDPE plant is about $220 million, and the operating cost for butene-based LLDPE production is about $1,220/ton.

The swing process depicted here allows manufacturers to participate in major PE market segments by producing both LLDPE and HDPE resins. Thus, the producers can select the best product mix, aimed at premium markets with higher margins. ■

Edited by Scott Jenkins

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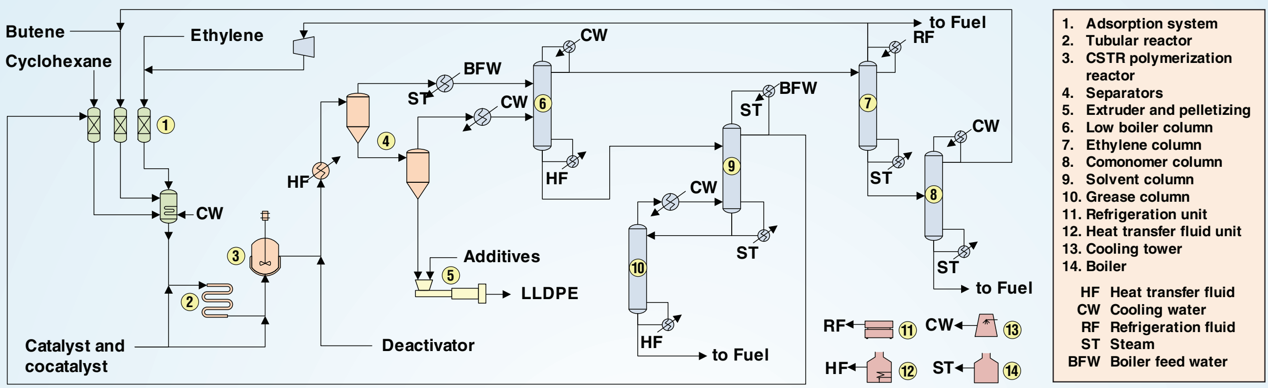

FIGURE 1. Solution-phase LLDPE production process similar to Nova Chemicals' SclairTech

Securing Industrial Control Systems

ICSs are vulnerable targets to cyber attacks. More than conventional IT-security solutions are needed to protect them

Andrew Ginter
Waterfall Security Solutions

Security of SCADA (supervisory control and data acquisition) and other industrial control systems (ICSs) is a complex subject, and one that has received much attention in recent years. While modern industrial control systems use many of the same computers, operating systems and networking components as conventional business networks, the two kinds of networks are managed very differently. As a result, what is "common wisdom" on business networks can be utter nonsense on control system networks.

On the other hand, control system networks are notoriously vulnerable to certain kinds of attacks, and whether common security wisdom works on these networks or not, these vulnerabilities must still be addressed. This article looks at what the differences between control-system and business networks are, what is working and what is not, and at what leading security practitioners in the chemical process industries (CPI), as well as other industries, are doing to address these problems.

Safety first

Cybersecurity concerns for business networks are prioritized according to "confidentiality, integrity and availability," in that order. Most existing advice for industrial cybersecurity suggests that on industrial networks, these priorities are often reversed so that availability and integrity are the highest priorities for industrial networks. While this was the best wisdom available when much of this advice was written, we know better now.

Every time any group of people at a chemical facility gathers for a meeting, the first order of business, without exception, is safety. The discussions include familiar statements, such as "Are there any newcomers in the group? A long, continuous alarm means evacuate the building. The emergency exits are around the corner to your left," and so on.

Safety is the highest priority at every industrial site, and also for every control system network. For every change to any control system component we always ask "how likely is it that this change will kill anyone?" or "will it create a public safety risk?" or "will it cause an environmental catastrophe?" When we have acceptable answers to those questions, we ask "how likely is it that the proposed change will so badly impair the operation of the control system that we are forced to shut down this billion-dollar physical asset, because we are no longer confident of our ability to operate it safely?" Safety is always our first priority, and reliability is our second. And yes, sometimes we have trade secrets to protect as well.

What does this mean for cybersecurity? Consider the business network in any large enterprise. Millions of Web pages and hundreds of thousands of emails are pulled into the network every day. Each of those Web pages and each of those emails is a potential attack. Business networks are under constant attack. How do professionals deal with this constant, pervasive threat? In part, they deal with it through constant, aggressive change. "Stay ahead of the bad guys." Update anti-virus signatures several times per day. Apply the latest vendor security updates within two days of the vendor's release.

This is the exact opposite of how control system networks are managed. Control system networks are generally configured to be unable to exchange information directly with the Internet, and so are not under constant attack. The biggest risk to industrial networks is the connection to the business network.

The discipline used to keep a control system safe and operating reliably is called "engineering change control." Every change to a control system is a potential threat to safety and reliability. Anti-virus signatures can cause "false-positive" matches that shut down and quarantine essential parts of control system software. Security updates can contain arbitrary changes to operating system and application code, and must be assessed, tested and very cautiously rolled out in order to preserve safety and reliability. Because of their constant change, anti-virus systems and security updates are very costly programs to roll out on control system networks, and everyone has a horror story to tell about the impact of these programs on — at least — reliability.

Vulnerabilities

The bad news is that vulnerabilities and security problems do not go away simply because IT (information technology) solutions to those problems work badly. Control system software is notoriously vulnerable to even very simple attacks. Back-of-the-envelope calculations suggest that there are at least 100,000 buffer-overflow vulnerabilities, alone, waiting to be discovered in control system software. Security researchers who look for vulnerabilities confirm this calculation. They report that after only a morning's effort, they typically find up to a dozen critical vulnerabilities in every bit of industrial software product they examine.

The problem is not limited to buffer-overflow vulnerabilities. Until very recently, cybersecurity was simply not a design criterion for industrial-software product development. Industrial control-system products are notoriously vulnerable to everything from SQL (Structured Query Language)-injection attacks, to hard-coded vendor passwords, to simple denial-of-service network flooding attacks.

A confusing factor associated with these vulnerabilities has been the "responsible disclosure" debate. How should new vulnerabilities be disclosed? Responsible disclosure holds that details of newly discovered vulnerabilities should not be disclosed publicly until the vendor has had an opportunity to produce a fix for the problems, and anti-virus and intrusion-detection vendors have had an opportunity to craft new signatures. Security researchers who have disclosed vulnerabilities outside of this process have been sharply criticized.

But think about it — how much less secure are we if someone publishes a serious security vulnerability in industrial software before a fix is available? Most industrial sites are unable to apply security updates in a timely manner because of safety-and-reliability-focused testing requirements, even if those updates are available. Worse, any attacker worth their salt can spend a morning with the software and find their own half dozen "zero-day" undisclosed, critical vulnerabilities themselves. They don't need disclosed vulnerabilities when finding their own undisclosed ones is trivial.

The extreme vulnerability of control system software is compounded by well-known problems, such as the use of plain-text communications protocols and very old software components. An attacker with access to an industrial network can simply send plain-text commands to any device on the network and those devices will carry out the commands without question. Very old equipment presents a similar problem. How many anti-virus vendors still support their products on Windows NT systems? Does Microsoft issue security updates any more for Windows 2000 systems?

All of these problems will take a very long time to solve, if that is even possible. Control systems administrators have proven to be very reluctant to deploy device-communications encryption because of the impact on maintainability and reliability. Old software versions on old operating systems are often essential to the operation of old equipment — equipment that is extremely costly to replace, because the testing and scrutiny necessary to ensure that replacement hardware and software are sufficiently reliable and are configured and deployed correctly.

Deploying a new version of software is more than a process of a little testing. Deploying sweeping changes to control systems or to the physical process itself, as often occurs at long intervals during site refurbishment, is a daunting task. The task involves months and even years of planning, then an intense burst of effort deploying and upgrading everything, and then additional weeks of "all hands on deck" effort to bring the plant back online, safely, to full production.

Take all this together and it is easy to see that while control systems use technologies that are similar to IT systems, control systems are constrained in ways that are alien to IT systems. As a result, a wide array of IT-style cybersecurity approaches are either ineffective on control systems, or are in fact counter-productive on control systems, resulting in net impairments of safety, or reliability, or both.

Cyber-threat spectrum

If control systems are more vulnerable than IT systems, what are they vulnerable to? Who are we worried about? Today's cyber-threat spectrum is outlined in Table 1.

Organized crime. Organized crime is still responsible for the vast majority of malware circulating on the Internet. Professional virus authors produce products that steal credit-card and banking information, and that harness compromised machines to send spam and launch denial-of-service attacks. Organized crime has resources (money and talent) to spend producing sophisticated attack tools. And by and large, the resulting attacks are autonomous — they spread automatically to as many machines as possible.

Insiders. Disgruntled insiders are a perennial threat, one typically dealt with via personnel and background checks, as well as via detailed auditing. With sufficient auditing, it is difficult for an insider to be confident of causing damage without being caught and prosecuted. In addition, well-meaning IT-security practitioners — who do not have a clear sense of the change-control discipline that must be applied to safety-critical and reliability-critical networks — are a special problem. These individuals may not mean to do harm, but examples abound where IT administrators with the passwords and permissions to reach through firewalls and modify systems by remote control have "applied corporate policy" to critical networks without understanding the consequences of undisciplined change, and have caused plant outages or batch failures as a result.

Advanced/targeted attacks. These are the so-called "advanced persistent threats," which have been in the press for some years. These attacks are generally attributed to nation-state military and intelligence agencies. These organizations have tremendous resources (money and talent) to direct at the problem of attacking specific targets. These adversaries have repeatedly demonstrated the ability to bypass conventional IT defenses. These attacks have been credited with the theft of source code, trade secrets, and other intellectual property valued at up to several trillion dollars. The preferred method of attack of these adversaries is low-volume malware that is operated by interactive, manual remote control. They spread cautiously so as to avoid detection and they steal enormous amounts of information, or more. While information theft is by far the most common motive for these targeted attacks, cases of sabotage have also been reported using these same techniques.

Cyber cold-warriors. This class of attacks does not have a widely accepted name. Some lump these attacks in with "advanced persistent threats" but the methods and objectives of this class of attack differ sharply from that of the advanced attacks. Some call this class of attack "cyber warfare" and maintain that a "cyber war" is in progress. This is akin to saying a "naval war" is in progress, without war having been declared, and without any other kinds of military forces having been mobilized.

In many senses, this class of attack has more to do with cold war tactics than with anything else. Stuxnet is credited with destroying 1,000–2,000 Iranian uranium gas centrifuges. The worm was apparently crafted using detailed insider knowledge of the control system, which was the target of the attack, and with similar knowledge of how that target was defended. The Shamoon attack is credited with effectively erasing the hard drives of over 30,000 computers in Middle-Eastern petrochemical firms. There is speculation that the worm was planted in the target networks by insiders. The motive of this class of attacker is clearly sabotage, and the preferred "weapon" is malware that spreads and operates autonomously.

Much has been written about Stuxnet specifically, and how to defend against the worm. Much of that information pits the artifact, which is the Stuxnet worm, against one kind of cybersecurity technology after another. "This technology would have stopped the worm" but "that technology would not have." Such analysis very much misses the point.

For every defensive technology deployed, there is an offense or attack that will defeat the technology. There are no silver bullets. If a site has trusted, "sleeper" insiders planted in its workforce decades ago by enemy nations, and those insiders are exposing detailed intelligence as to the design of the control system network and of the control-system cybersecurity defenses to enemies willing to spend tens of millions of dollars to devise an attack specific to that site, then that site does not have a cybersecurity problem. That site has an espionage problem. No additional cyber-defenses will prevent a Stuxnet-class attack. A site with this kind of problem needs to escalate the problem to its own national intelligence authorities.

"Advanced persistent threats" are a different matter. It is absolutely possible to protect industrial sites against these attacks, but there is a strange reluctance in some organizations to apply the protections. The reason is that so far, the vast majority of these incursions have had only industrial espionage — stealing information — as a motive. Some industrial sites feel this is reason to be complacent, because they have no information that is worth stealing, and so they feel they will never be targeted.

This is akin to saying "There is a hole in our perimeter fence, and heavily armed criminals are wandering in and out through the hole at will." And then saying "But that's OK, all they want to do is steal stuff, and they aren't finding what they want to steal in our site so they're really not doing that much damage." This is nonsense. Anyone with this kind of hole in their perimeter would say "Close that hole. Close it now." Unauthorized, untrained individuals on the other side of the planet with remote control of industrial control

TABLE 1. THREAT SPECTRUM

Threats	Resources	Motives	Methods	Examples
Cyber cold-warriors	High	Sabotage	Highly targeted, autonomous	Stuxnet, Shamoon?
Advanced threats	High	Industrial espionage	Targeted, manual remote control	Flame, DuQu, Gauss, APT
Targeted attacks	Medium	Industrial espionage	Targeted, manual remote control	Night Dragon, hacktivists
Insider with ICS network access	Low	Sabotage	Targeted: social engineering	Maroochy
Insider with IT network access	Low	Sabotage, or benign	Targeted: social engineering	IT errors and omissions
Organized crime	Medium	Identity theft, spam, distributed denial of service	High volume, automated	Zeus, Conflicker

"ADVANCED THREATS" — HOW DO THEY DO IT?

"Advanced" attackers have demonstrated that they can bypass conventional IT cybersecurity mechanisms, essentially at will. They have demonstrated that they can take over industrial control-system computers just as easily as they take over IT systems.

The disturbing thing about these attacks is that while they are called "advanced" — and they sometimes do use very clever malware — the majority of these attacks are not terribly advanced at all. Most often, these attackers simply apply basic security-hacking techniques — the techniques taught at widely available, legitimate security-training programs. Persistent application of these techniques is all that is required in order to breach IT defenses, even at very large, and presumably very well-protected organizations. The techniques include the following:

1. Do homework on social networking sites. Learn everything possible about a handful of target individuals at the target site
2. Craft custom malware that anti-virus systems have never seen before. Attach the malware to a very convincing forged email, or via a link in the email
3. Send the email and trick the target into executing your malware, which then connects to an internet command-and-control center for instructions
4. Over time, send instructions via the control center, to learn about the target's network and steal passwords
5. Take over a domain controller with stolen administrator passwords. Create accounts for attackers on VPN servers, business computers and industrial computers
6. Log into computers with new or stolen passwords — there is no need to "attack" vulnerabilities any more
7. Search for the information of interest and steal it ❑

system computers are a safety threat. They need to be stopped.

Old-school defense in depth

What are different kinds of organizations doing about these threats and these vulnerabilities? The common wisdom, among both industrial security practitioners and IT security practitioners is "defense in depth." Given that for any defense, there is some kind of attack that will get around it, standard advice is to put many layers of defense in place in order to slow down attackers and to increase the probability of identifying and neutralizing the attacks before they do damage.

In recent years, anti-virus systems and security-update programs have been widely deployed in the CPI. By the standards of most industries, chemical plants are huge. These protections have been deployed in spite of their limited effectiveness due to enormous numbers of latent vulnerabilities, and huge numbers of run-of-the-mill viruses being created every day. CPI sites are deploying anti-virus and security-update programs, and are absorbing the significant cost of these "constant change" security programs.

Old-school "defense in depth" wisdom, as expressed in documents such as NIST 800-82, the DHS Defense in Depth Guidelines and the ISA SP-99 standards, generally includes IT-type protections, including intrusion-detection technologies. The theory, espoused for years, is that intrusion detection is always the last line of defense. This theory has gained widespread acceptance in IT circles in recent years because of the widespread success of these "advanced/targeted" attacks. Organizations are no longer confident of their ability to block targeted attacks at their IT network perimeter, and are deploying internal protections and surveillance. Common wisdom is evolving to hold that "until you assume you have been compromised by this class of adversary and you start looking really hard for these attacks, you will never find them — they are that good."

As a result, organizations are deploying intrusion-detection technologies of various types on corporate networks. They are sometimes deploying these technologies on industrial networks, and they are gathering all of this cybersecurity surveillance data together into security information and event management (SIEM) systems to try to make sense of it and find enemies on the networks.

This common wisdom is not wrong. Intrusion detection is always the last layer(s) of defense-in-depth strategies, even though intrusion detection may be costly to deploy. Why is this? An intrusion-detection system is not effective if you tune it so aggressively that it never raises an alert, even if there is a real intrusion. Tuning a detection system less aggressively yields a certain number of false alarms or "false positives" from time to time, and every alarm must be investigated to determine if it is a real intrusion or a false alarm. As anyone in the physical security realm knows, surveillance is costly, and responding to false positives costs even more.

This common wisdom is not wrong, but it is not completely right either, or at least it is not the whole story. In the last half decade or so, a number of technologies have been developed that add different and very effective layers to defense-in-depth programs, but these technologies are not yet represented in standards and guidance.

These additional layers go by the name of "compensating measures." When security vulnerabilities cannot be eliminated directly, either because there are too many undiscovered vulnerabilities, or because the security updates cannot safely be deployed in a timely or cost-effective way, sites in many industries are deploying compensating measures.

Safety and protection systems

One widely applied tactic, for example, is to increase the investment in a variety of mechanical, electro-mechanical and digital safety systems and equipment-protection systems. These systems are designed to constantly monitor for unsafe conditions, and bring the plant back to a "known safe state" if an unsafe condition is detected — often by triggering a safety shutdown of one of the large systems in the plant, such as a boiler or a catalytic cracker. Safety systems are designed to protect human life and the environment, while protection systems are designed to protect equipment from damage. Often protection systems have indirect safety benefits, since conditions that are able to cause damage to very large equipment are frequently also dangerous enough to pose a threat to workers and the environment.

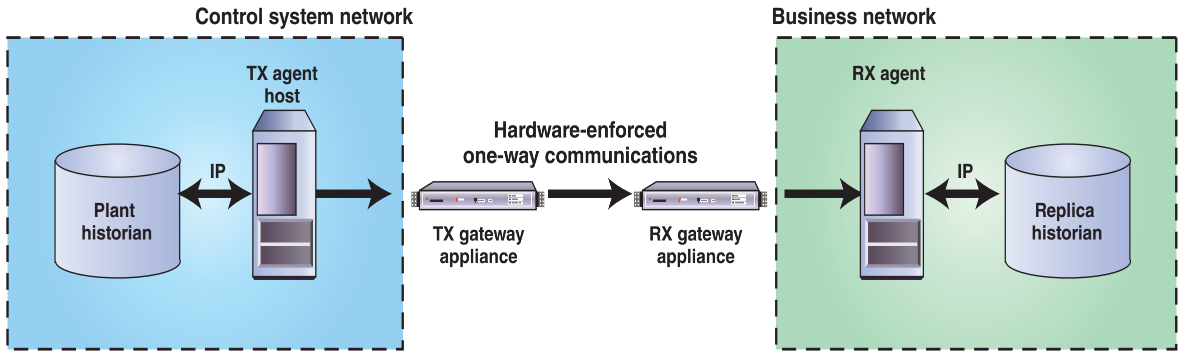

FIGURE 1. Unidirectional security gateways can replace one or more levels of firewalls. In this example, the RX software on the outside network populates replica servers with the data

The goal is to design safety and protection systems so thoroughly that no matter what the cyber attack, these systems are able to detect unsafe conditions and trigger a safe shutdown. To accomplish this cybersecurity function, the safety and protection systems must themselves be thoroughly protected from attack, often by physically controlling access to the systems, and by isolating them, to some degree, from the plant network. If this design succeeds — and protecting against all possible cyber-sabotage is not easy — then the cyber threat is reduced to a threat to reliability only, not a threat to safety. In many industries, reliability is a business problem, not a public safety problem, and can be addressed with mechanisms such as buying insurance if additional cyber protections are cost-prohibitive. In other industries, such as the power grid, or in geographies where petroleum refineries or other installations perform functions that are essential to society or national security, reducing a safety threat to a reliability threat is a step in the right direction, but more action is needed.

Unidirectional gateways

Unidirectional security gateways are a security technology that replaces one or more layers of firewalls in a defense-in-depth architecture. The technology consists of both hardware and software.

The hardware is a pair of network appliances called gateways, connected by a short fiber-optic cable. The transmit (TX) gateway contains a laser, and the receive (RX) gateway contains a photocell. Together, the two are able to transmit information out of a control system network, without any risk of any attack penetrating back into that network.

With firewalls, every connection through the firewall that allows data out of a network, also allows attacks back into the network. Firewalls do not provide access to data on protected networks; they provide access to systems on those networks. With the gateways, it does not matter what kind of attack is launched on the receive-side of the gateway — no signal at all, not a message, not a byte, not a bit — can pass through the unidirectional hardware to interfere with the safety-critical or reliability-critical network.

Now, since nearly all modern communications protocols are fundamentally bi-directional, no normal protocols can be used to push data through the unidirectional hardware. Instead, the gateway software replicates servers. The software runs on conventional computers on the control system and external networks. The TX software on the control system network gathers data from servers, such as production historians, or OPC servers, or even PLCs (programmable logic controllers), which are "Modbus servers" in TCP (transmission control protocol) parlance. The data are sent over the unidirectional hardware using custom protocols. The RX software on the outside network populates replica servers with the data. Users on the outside networks access the data they need by connecting to the replica servers. Server replication is, in general, very possible. Protocol emulation or "proxies" generally are not possible over unidirectional hardware.

This technology is being deployed widely in conventional power generation as well as nuclear-power generation plants. The cybersecurity regulations for nuclear power generation have encouraged hardware-enforced unidirectional technology for some years already. In more conventional power generation, the new North American Electric Reliability Council (NERC) critical infrastructure protection (CIP) regulations (NERC-CIP V5) have been updated to recognize the strong security offered by this alternative to firewalls.

Power plants — even nuclear sites — tend to be much smaller and simpler than chemical plants or petroleum refineries, though. Most deployments in the power industry use the gateways to replace the layer of firewalls between the plant network and the business network at a site. At CPI sites, deployment models are more varied. Some sites are deploying the gateways at the high-volume connection between the plant network and the business network, but not all of them. Some large sites are associating their reliability-critical assets with smaller control network segments. These sites manage the plant-wide network in much the same way as their corporate network. These sites deploy the gateways deeper into the defensive architecture, replacing either the firewalls protecting individual DCSs (distributed control systems), or sometimes the firewalls at the perimeter of safety and protection systems.

In principle, safety and protection systems really should not be connected to control networks or plant networks at all. These systems should be as safe from outside interference, and as tightly change-controlled, as possible. In practice, there is enormous value in monitoring all equipment at a site, including the health and activity of safety systems. Connecting these systems to networks via firewalls is dangerous. Making data from safety and protection systems available to outside consumers using hardware-enforced unidirectional gateways is much safer.

Application control

An infected USB stick could still be carried into the industrial network. To protect this "soft interior" of control system networks, industrial sites are starting to deploy application control software, or "whitelisting" as it is sometimes called, to protect the interior of industrial networks. These systems are effective at controlling the execution of software, not just from hard drives on industrial systems, but also software coming in via USB sticks and other removable media as well.

Application control systems work by producing a list of software that is allowed to run on a protected computer. This list may include names, signatures, cryptographic checksums and other characteristics. When a program asks to run another program, or to load a library, the application control subsystem springs into action. Application control asks the question "is the requested software allowed to run?" by checking the characteristics of the software against the allowed list. If there is a match, the software is allowed to run. If there is no match, then this software has never been seen before, and is not permitted to run.

Contrast this with anti-virus systems, which generate lists of millions of signatures, trying to identify specific pieces of malware that should never be allowed to run. New malware exploiting zero-day vulnerabilities takes time to appear on the list. Custom malware that is used to attack one site, and none other, will never appear on a signatures list. Application control simply blocks all software that is not explicitly approved to run, assuming that everything new or changed is forbidden, no matter whether the software comes from a USB stick or a network connection.

The "allow only known good software" approach is a good match for change-controlled networks. On such networks, every unauthorized, untested change is a threat to safety and reliability. Application control adds extra steps to the software deployment process, but these are exactly the steps that change-controlled environments demand. The extra steps validate the changed software, add it to "allowed" lists, and send those lists to equipment where it is safe to execute the new software.

Application control is recognized in the new CIP V5 standards protecting the power sector. It is supported by a growing number of control system vendors, and is starting to be deployed in control systems in many sectors. The vendors who are most mature in terms of their adoption of this technology are the device vendors. A good number of modern PLCs and other industrial devices are based on realtime Windows-operating-system variants of one sort or another. These vendors are embracing the application control approach because their embedded Windows systems are seen as uniquely vulnerable. These systems often cannot be updated to the latest Microsoft security updates in a timely way, and so benefit disproportionately from the strong security protections offered by application-control systems.

Looking forward

The SCADA/ICS security picture is a complex one. This article has focused on emerging trends rather than measures that most sites are deploying routinely, such as using physical security as a compensating measure for control system vulnerabilities, or using additional layers of firewalls as a compensating measure for plain-text communications.

SCADA security programs can become very confused when "IT experts" not familiar with safety-critical or reliability-critical change control imperatives are put in charge of security programs. This confusion is becoming commonplace, as the trend is toward consolidating operations network engineering and cybersecurity teams with corporate IT teams under a single CIO/CSO executive.

CIOs need to start asking their IT security experts the same questions that operations teams are asking those experts: "how likely is it that this change you're proposing will kill one of us?" CIOs need to start asking which operations-specific security technologies these experts are considering, or if they are simply assuming that confidentiality-protecting technologies will somehow also work to protect safety and reliability.

CEOs need to start asking their CIOs what they are doing to protect the safety and reliability of the plants controlled by the industrial systems those CIOs now have authority over. What programs are in place to ensure that leading-edge safety-preserving and reliability-preserving technologies and approaches are in place, in addition to the confidentiality-preserving systems the CIOs have known about for decades?

SCADA security is difficult. Blindly applying conventional IT security solutions to safety-critical and reliability-critical systems is a costly undertaking, and the constant change that comes with such programs increases, rather than decreases, the risk of plant outages. While cybersecurity for industrial control systems is not easy, it is do-able, provided we keep safety and reliability priorities foremost in our minds. ■

Edited by Dorothy Lozowski

Author

Andrew Ginter is the vice president of Industrial Security at Waterfall Security Solutions (Calgary, Alberta, Canada; Email: andrew.ginter@waterfall-security.com; Website: www.waterfall-security.com). He spent 25 years leading the development of control-system software products, control-system middleware products, and industrial cybersecurity products. Ginter represents Waterfall on ISA-SP99, NERC-CIP and other cybersecurity standards bodies, and writes and speaks frequently on industrial cybersecurity topics. He holds a B.Sc. in applied mathematics and an M.Sc. in computer science, both from the University of Calgary (Alta., Canada).

Lifecycle Costs for Capital Equipment In the CPI

Longterm equipment costs need to be fully considered in capital-cost assessments

Jeff Hoffmann
Paul O. Abbe

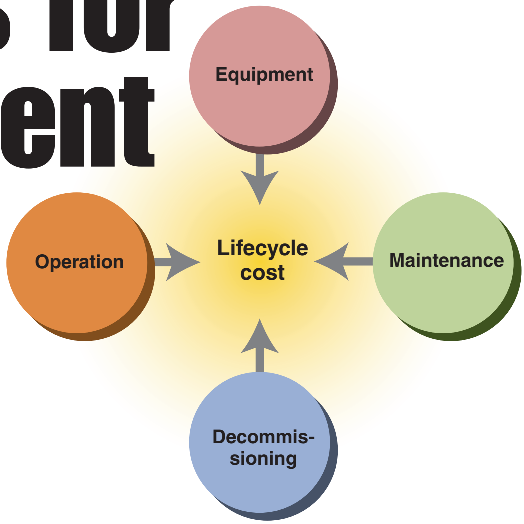

FIGURE 1. Initial capital costs alone are too often the primary criteria for selecting process equipment

When considering project proposals for new processes in the chemical process industries (CPI), capital equipment costs often become the primary focus. The purpose of this article is to provide a detailed examination of the total cost of process equipment and the implications that the initial equipment cost has for longterm costs over the full life of the process.

Aside from equipment costs, other critical costs to consider include, operation, maintenance and decommissioning (Figure 1). Also, since a process generates revenue only when it is operating, downtime must be added to the total costs. When the whole lifetime of a process is considered, equipment costs may account for as little as 5–10% of the total cost (Figure 2).

There are a number of questions that should be considered before moving ahead with projects. How should you define the product output, quality, unit operations, support equipment and profitability? Who is responsible for operating and maintaining the process? Do the demands for process performance conflict with operating and maintenance realities? What is the likelihood that the equipment will operate trouble-free? Are replacement parts available for both routine and non-routine maintenance?

Minimizing total cost

The emphasis on total operating costs over the life of a process does not imply that the initial equipment costs are unimportant. On the contrary, it is precisely the investment in the correct equipment in the first place that is to be examined. The purpose of the procurement of process equipment is to perform a particular function within a unit operation. The goal is not the purchase of a particular piece of equipment. If we add the dimension of time, then our definition for process equipment becomes a piece of equipment that performs a specific function under various conditions over a prescribed period of time. Therefore, we should not focus on equipment with the lowest initial cost, but rather on the realistic longterm cost of that purchase.

In the early 1980s, Edward Deming — the father of quality management — stated that organizations should "end the practice of awarding business on the basis of price tag alone and, instead, minimize the total cost." This sentiment is consistent with evaluating lifecycle cost.

Lifecycle cost

The purpose of lifecycle-cost (LCC) analysis is to make informed decisions based on available alternatives in order to achieve the most economical process from inception to decommissioning. LCC takes into account the design, equipment selection, operation, maintenance and final disposition costs of a project over its lifespan. LCC is useful for engineers in justifying equipment and process design based on total costs rather than the initial purchase price of equipment alone.

Procurement strategies focused on lowest initial costs are more likely to lead to higher longterm costs. We are often directed to reduce costs and work within budgets. In the short run, this approach can make us and our department appear efficient. However, the lower initial capital costs may come with maintenance or other problems that eventually will be realized by the company shareholders in the coming years and decades. LCC can help avoid unnecessary downtime and help make a process more competitive and profitable. At the very least, an LCC analysis may prompt engineers to consider a wider range of possibilities.

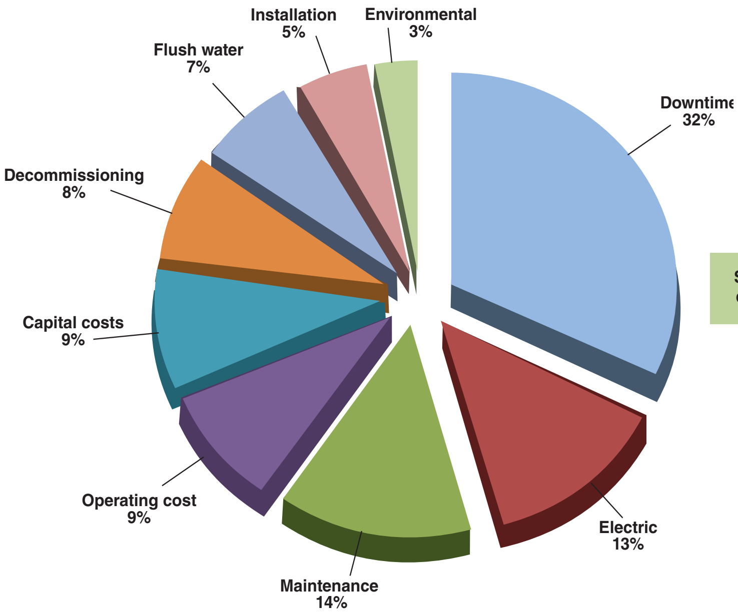

FIGURE 2. Initial capital costs represent a small fraction of the total lifecycle costs for process equipment. The graph depicts the case of a "worst case" situation with considerable downtime costs (see Table 1, scenario 1, p. 41)

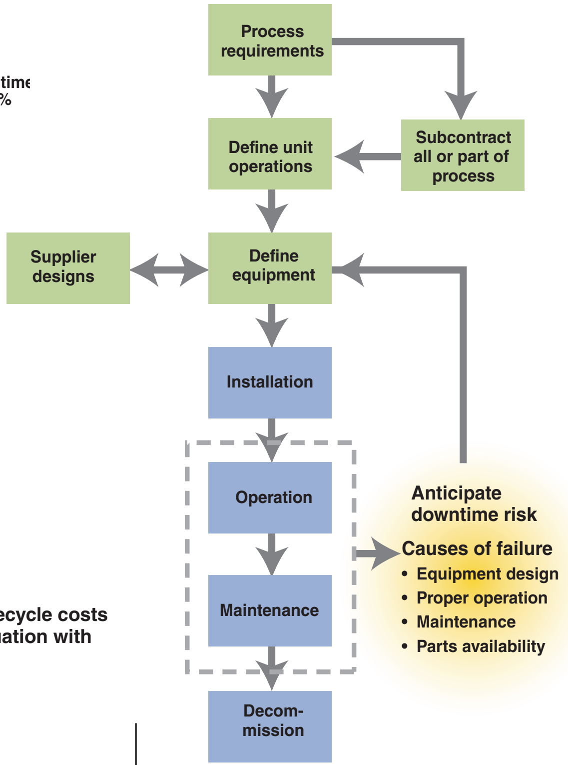

FIGURE 3. The LCC analysis process shown here is designed to minimize total cost, even if initial capital costs are higher

The remainder of this article presents a more-or-less qualitative view of the LCC analysis process and the elements that go into LCC. The "Further reading" list at the end of the article refers readers to several more analytic versions of LCC, including Weibull analysis, risk-based cost analysis, Monte Carlo modeling, and other "what-if" analyses.

The main goals of LCC are: 1) To identify risks to process operation and efficiency; 2) Quantify these risks in terms of downtime; and 3) Determine how to avoid these risks and subsequent losses early in the design of the system (Figure 3).

LCC for the CPI

Of all the industries and all the types of manufacturing plants in the world, it is safe to say that the process industries are some of the most variable and complex. With more than 70 million identifiable chemicals and a near-infinite number of combinations, and given the number of unit operations possible, there are many opportunities to examine process costs. The four primary components involved in the LCC are:

- Capital equipment costs
- Operating costs
- Maintenance costs
- Decommissioning costs

These components are further subdivided (Figure 4).

STEPS IN LCC ANALYSIS

LCC considers everything in the life of a process, starting with a definition of the process, its unit operations, and the equipment required to fulfill those unit operations, as well as operating costs, maintenance costs and finally decommissioning costs. The following are the major steps involved in determining LCC.

Assess process requirements.

Tasks to consider when undertaking a new process include the following:

- Determine present and future capacity for the product
- Anticipate the lifetime of the process. Some processes may have a lifespan of anywhere from a year or two to decades. Anticipating process lifetime will either concentrate or extend cost impacts and affect the long-term maintenance and reliability of the process
- Define product quality based on customer requirements
- Determine process flexibility. How easily can the equipment and system be modified to accommodate increased output of product, changes in formulation or the addition of a step in the process?
- Quantify waste. What percent of waste is acceptable? What is the cost of waste disposal? How can waste be minimized by a change in the process? Can off-specification product be reprocessed or sold "off-spec" to a different market?

Define unit operations

This step involves identifying the unit operations and types of equipment required by the process.

Subcontract. Subcontracting one or more operations in a process is something often overlooked, but can increase cost efficiencies and flexibility. Few manufacturers of process equipment manufacture everything — motors, gear drives and bearings are not manufactured in-house. Likewise, chemical companies do not manufacture all of their raw materials, nor do they necessarily perform all tasks in-house. Subcontracting is, for most businesses, a matter of degree rather than a yes-or-no decision. Some steps in a process may not be cost-effective to execute in-house. For example, high-pressure reactors, spray-drying or packaging may best be outsourced operations, at least until the operation grows and the investment can be better justified.

Continuous, batch or a combination. The decision for a continuous or batch process (or a combination of the two) is sometimes dictated by the process, and sometimes optional. Within this decision, a set of factors should be considered:

- Continuous process operations can often have much higher output and may require less equipment, but they may have more variability in quality and reworking off-spec product in a continuous process may be difficult
- Batch operations may require more storage and intermediate buffer tanks and larger equipment, but they have the advantage of consistency and often have a better chance to re-work off-spec product

Storage strategy. In anticipation of routine or emergency shutdown, a storage strategy should be created. Can the finished product be stored and, if so, can the downstream process or packaging accommodate a surge in capacity?

Process bottlenecks. Which aspects of the process have the most variation? For example, liquid mixing is fairly consistent, whereas solids drying can vary considerably with particle size. Does a dryer need excess capacity? Evaporator capacity can fall off quickly due to tube fouling either on the product or heat-transfer-fluid side. In the example on page 39 (Figure 5), the performance of the evaporator falling below 600 gal/hr can be the result of scale build-up or fouling. Investing in a water demineralization system may be worthwhile if the bottleneck affects productivity and profitability. Likewise, too large an evaporator with low velocity may be more prone to fouling. Bigger is not always better.

Define required equipment

Process equipment has many variations in basic design and design options. Discuss your requirements with equipment manufacturers and gather information on: performance; design; options; installation; foundation and support requirements; utility requirements; mean-time between failures; and recommended spare parts for the first few years of operation. This is also the time to start gathering information on refurbished and used equipment (discussed later). The steps are as follows:

1) Identify suppliers and dealers for new versus used versus reconditioned equipment. Identify alternate designs (for example, shell-and-tube versus plate-and-frame heat exchanger, or fluid-bed versus vacuum dryer).

2) Identify design features that may improve product quality, increase uptime and reduce maintenance. These might include automatic lubrication, and monitoring devices for vibration, over-temperature and low-level protection. Evaluate whether a clean-in-place (CIP) system would be cost-effective, or whether the equipment would be better cleaned manually. Also, it is important to understand what level of operator exposure to product and cleaning chemicals is acceptable. Other options might include maintenance-reducing features, such as additional access hatches, sight glasses and lights, split seals and bearings and replaceable wear liners.

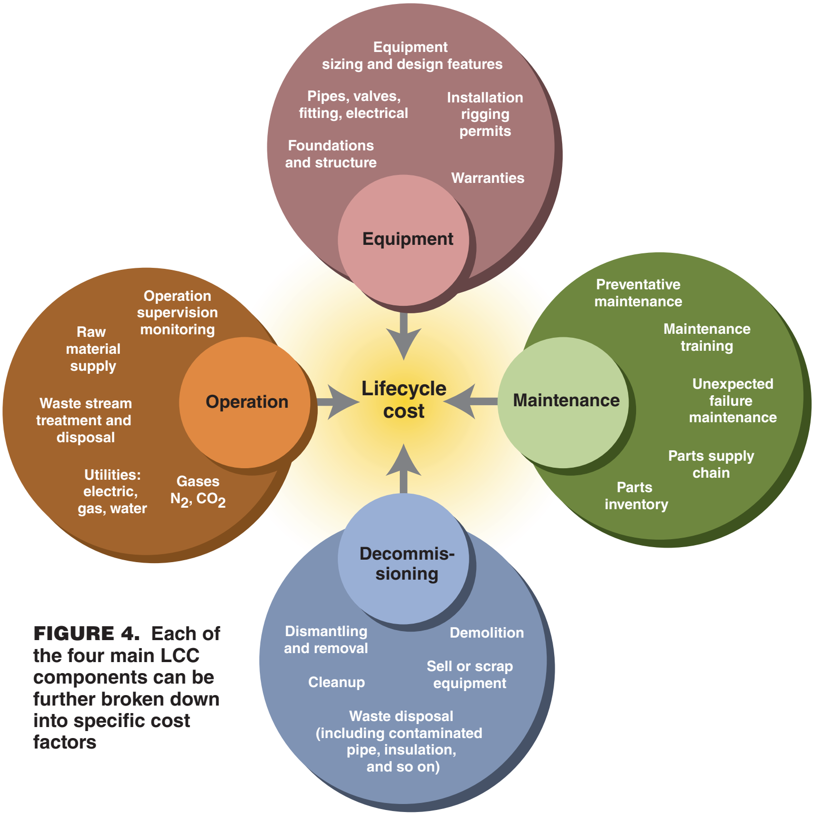

FIGURE 4. Each of the four main LCC components can be further broken down into specific cost factors

Equipment installation

Installation costs may equal or exceed equipment costs, depending on the size and complexity of the equipment. An important consideration during the layout and installation of equipment is the accessibility to allow preventive maintenance and future repair. Sufficient space must be provided for the extraction of shafts, rotors and motors, as well as to provide access to seals and bearings. Overhead structure should allow for portable hoisting chains or permanently installed hoists.

Although not routine, anticipating the removal of large pieces of equipment should not be made impossible

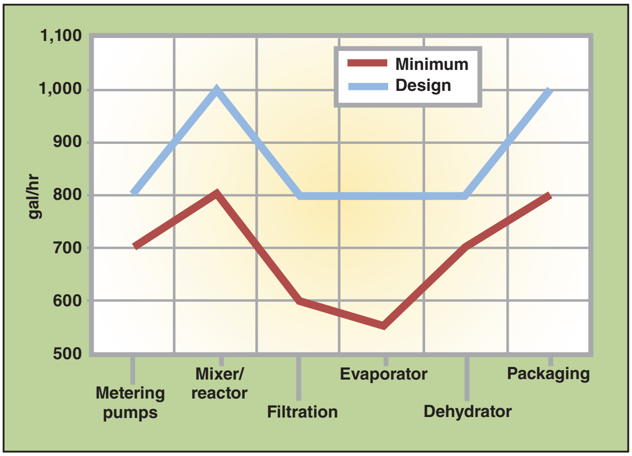

FIGURE 5. Certain aspects of a process have higher potential to present process bottlenecks than others

by physical constraints. Without clear access, preventative maintenance may suffer and repair time may be extended. Factors involved in the installation cost may include the following:

- Machine foundations
- Accessibility for maintenance and repair
- Support structures and mezzanines
- Piping, valves and fittings
- Instrumentation
- Electrical controls
- Monitoring equipment
- Electrical switchgear

Operation

Operation and maintenance are two areas that are critical to avoiding downtime and both are affected by equipment selection, design and operating procedures.

If the equipment was sized properly, there should be no reason to operate it beyond safe design capacities. Many types of equipment are tested at, or designed for 150 to 200% of the rated capacity, but operating at these capacities may risk shortening the life of the equipment. Other aspects of operation costs include the training of operations personnel, utilities (electricity, gas, water, steam and cooling tower capacity) and the time that the equipment is offline for preventative maintenance.

The costs of raw materials, water treatment (demineralizing, pH adjustment), purge gas (N_2, CO_2) and waste disposal are also key operations costs. Most CPI processes, even in the food industry, have to dispose of waste product or waste streams from washing, off-specification product or simply contaminated water coming from a wash step.

Maintenance

Generally, maintenance can be classified into two types: preventative and repair. Some failures occur randomly and cannot be predicted, but other failures occur as a result of a lack of preventative maintenance (PM).

PM is an area that has evolved into a service that can be subcontracted and may be economical when considering the total longterm value provided. PM companies often have superior knowledge of pumps, drives, lubrication and routine maintenance issues, including good record keeping. The PM record keeping can also help support any warranty claims and avoid disputes with original equipment manufacturers (OEMs). The cost of subcontracting PM must be considered against the benefits of avoiding downtime. Parts availability is important in avoiding downtime both for PM and unexpected failures. Questions to consider in having parts available when required are the following:

- Do you know the supply chain for the parts you need?
- Do you know your OEM parts and service contacts?
- Are you considering non-OEM or counterfeit parts?
- Do you have a recommend parts list for each machine for the first few years of operation?
- What are the availability of standard parts?
- What is the availability of special non-standard parts?
- What is the cost to purchase and stock the recommended parts?
- Will your OEM put consigned stock in your facility? What is involved in administering consigned stock? Are you prepared to safely store and protect the parts?
- What is the cost to stock parts for catastrophic failures? Some large parts, such as motors, gear drives or centrifuge scrolls and bowls, can take weeks or months to obtain. The low probability of failure may be offset by the very long lead times and may require investment in costly parts that may sit on the shelf for years.
- Is maintenance staff knowledgeable and prepared to identify symptoms of failure early, and diagnose and repair issues quickly and correctly the first time? Check with the OEM for guidance and training. Do you have the installation and operating manuals on file? Have they been thoroughly reviewed?
- What are the anticipated preventative maintenance intervals?
- What is the expected time between failures for components like seals, and bearings, and the expected time between belt adjustments and filter replacements?
- Should all or some PM be outsourced?
- Does the OEM offer PM services?
- What is the repair turnaround time for a specific failure?

Decommissioning

The concept of decommissioning is not something most engineers tend to consider as they are designing a plant, but some plants will have finite lives of just a few years due to licensing agreements, patents, changes in markets or plans to shift to overseas production in the future.

Planning for decommissioning a process plant can vary from simple tear-down and selling of equipment to preparing for a sophisticated decontamination procedure. Chemical process equipment has special considerations that can increase the cost of decommissioning. Not only will

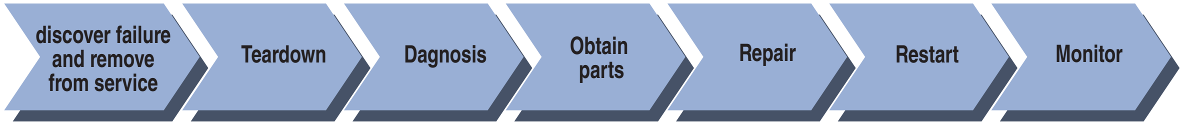

FIGURE 6. Downtime represents one of the most significant and costly issues for many processes

waste material have to be disposed of, but piping, insulation and flooring may have to be decontaminated or treated as hazardous waste.

Other costs of decommissioning include dismantling of equipment, waste disposal of chemicals (unused chemicals, water-treatment and cleaning chemicals, as well as those in above- and below-ground tanks, evaporation ponds and contaminated pipes).

Costs of downtime

Process downtime is one of the most significant and costly issues for many processes. To properly take into account the costs of downtime over the life of the process, engineers must estimate how much cost is accrued if the process fails, either in whole or in part. Further, once it fails, the question becomes how long will it take to restore operation?

In terms of equipment selection and design, which equipment and design features will be less likely to cause downtime? Which will be most easily maintained? How quickly can an expected failure be repaired so the equipment can be put back in service?

The risks and costs of process downtime can be considered in a semi-quantitative form by examining the likelihood of an event occurring in a given time period and the cost per unit time of that failure.

Downtime Cost = *frequency of failure / year*
x *downtime / days*
x *$ losses / day*

Downtime starts with the failure of the equipment and stops when it is put back in service. Better maintenance training can reduce the diagnosis and repair time significantly. The basic sequence is the discovery of a failure, followed by teardown, diagnosis, obtaining parts, repair, restart and monitoriing (Figure 6).

Events per year	Cost of event: $100	$1,000	$10,000	$100,000	$1,000,000
5	$500	$5,000	$50,000	$500,000	$5,000,000
4	$400	$4,000	$40,000	$400,000	$4,000,000
3	$300	$3,000	$30,000	$300,000	$3,000,000
2	$200	$2,000	$20,000	$200,000	$2,000,000
1	$100	$1,000	$10,000	$100,000	$1,000,000

FIGURE 7. A matrix can help quantify the costs of downtime in a process

One factor with a great impact on reducing downtime is the availability of parts. The parts may be common, such as O-rings or gaskets, seals or bearings, or they may be less common, such as pump housings or drive shafts.

If a complete shutdown costs $100,000 per day, the expected frequency of a catastrophic shutdown three times per year is a total of $300,000. For a non-critical failure that reduces productivity, but does not shut down the process entirely, an event cost of $50,000, with a frequency of five times per year would total $250,000 (Figure 7).

The following examples (Figure 8 and Table 1) emphasize maintenance training and parts availability in the prevention of downtime. Suppose the additional cost of training and parts is $80,000. With downtime cost at $20,000 per day, the investment of $80,000 saved $86,000 compared to without the training and parts after just one outage event.

In a second example, a $70,000 design feature reduces downtime by making a routine and expected part replacement faster, from three days to one day. Over the 10-year life of the process, the saving is $890,000.

Those examples represent the costs of just one critical unit operation and one design feature. When considering similar analyses across an entire plant, the cost savings can be substantial. The conclusion of the above is that a relatively small upfront investment may save considerable cost in the long run.

NEW, USED, REFURBISHED?

There is a saying that all process plants run on used equipment, and that is true. The LCC analysis is not prejudiced with regard to used or refurbished equipment — LCC considers the balance of downtime prevention and investment in equipment and preventative maintenance. If you know your process requirements and have the resources to keep used equipment functioning as reliably as necessary, then used or refurbished equipment is the right choice. There are several LCC issues to consider when deciding between new, refurbished and used equipment.

Not all buyers are in a position to

		Dwell time, days			
Sequential step	Event	Scenario 1	Scenario 2	Preventative action	Annual cost
1	*Discover failure*	1	0.1	Maintenance training	$ 30,000
2	*Teardown*	1	0.5	Maintenance training	
3	*Diagnosis*	1	0.5	Maintenance training	
4	*Accquire parts*	5	0.1	Parts in stock	$ 50,000
5	*Repair*	1	0.5	Maintenance training	
6	*Re-start*	1	0.5	Maintenance training	
7	*Monitor*	1	0.5	Maintenance training	
	Total days of downtime	11	2.7		$ 80,000
	Investment in training and parts	$0	$80,000		
	Downtime cost $20,000/day	$220,000	$54,000		
	Total	$220,000	$134,000		
	Additional cost of lack of preparation	$86,000			

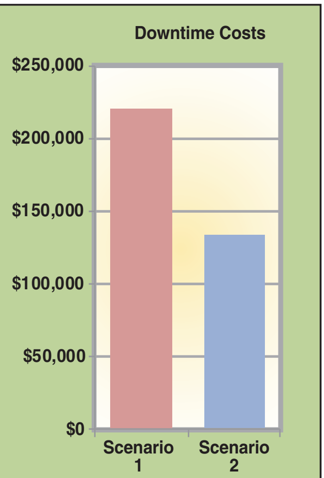

FIGURE 8. Different downtime scenarios for availability of parts and other factors can yield variable costs

TABLE 1. THE IMPACT OF VARYING DOWNTIME COSTS

Scenario 1 High-pressure reactor mixer	Year										
	1	2	3	4	5	6	7	8	9	10	Total
Initial capital costs	$380,000										$380,000
Installation and commissioning	$230,000										$230,000
Utilities - electric ($0.12/kwh)	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$600,000
- flush water ($0.04/gal.)	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$300,000
Operating costs (normal supervision)	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$400,000
Maintenance costs	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$600,000
Downtime costs ($48,000/d x 3 d)	$144,000	$144,000	$144,000	$144,000	$144,000	$144,000	$144,000	$144,000	$144,000	$144,000	$1,440,000
Environmental costs	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$130,000
Decommissioning										$350,000	$360,000
Total	$347,000	$347,000	$347,000	$347,000	$347,000	$347,000	$347,000	$347,000	$347,000	$697,000	$4,430,000
Scenario 2 High-pressure reactor mixer	**Year**										
	1	2	3	4	5	6	7	8	9	10	Total
Initial capital costs	$380,000										$450,000
Split seal and bearing option	$70,000										
Installation and commissioning	$230,000										$230,000
Utilities - electric ($0.12/kWh)	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$600,000
- flush water ($0.04/gal)	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$300,000
Operating costs (normal supervision)	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$400,000
Maintenance costs	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$600,000
Downtime costs ($48,000/d x 1 d)	$48,000	$48,000	$48,000	$48,000	$148,000	$48,000	$48,000	$48,000	$48,000	$48,000	$480,000
Environmental costs	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$130,000
Decommissioning										$350,000	$350,000
Total	$931,000	$251,000	$251,000	$251,000	$251,000	$251,000	$251,000	$251,000	$251,000	$601,000	$3,540,000

TABLE 2. COMPARISON OF NEW, USED AND REFURBISHED EQUIPMENT			
	New	**Refurbished**	**Used**
Application assistance	Application definition and machine design	Limited	Limited to none
Design features	Unlimited	Some variations or modifications possible as part of the rebuild process	None (whatever is in stock)
Delivery	4–8 months	1–2 months	Immediate
Price	100%	40–50% of new	20–40% of new
Mechanical warranty	12 months from installation or 18 months from shipment	90 days to a few months	None ("as is")
Right to return	None	None	10–30 days
Parts availability	In-stock or readily available	The fact that the unit is being refurbished indicates that parts are available from the OEM. Variable parts availability	Call OEM and find out how available parts are before purchasing. Parts availability diminishes with time
Aftermarket technical support	Complete technical support	Limited	None

purchase new equipment because of cost considerations or time. Used equipment may also be the appropriate alternative when time is a consideration, either in terms of delivery or usage. Used equipment is frequently available for immediate delivery, compared to the relatively long lead times that are typical of new capital equipment. In these cases, used equipment may provide the optimal alternative (Table 2).

The following scenarios favor the purchasing of used or refurbished equipment:

- When price is of prime importance because of investment limitations
- When the equipment is needed immediately for an emerging market
- When the equipment will be used for a limited time, such as a feasibility study or short-production run for a special product or market
- When the equipment can be economically modified to fit the purpose. This will have a lot to do with your ability to refurbish and maintain the equipment
- When the process is routine, low output or low risk. Infrequently run equipment will have more opportunity for PM and will be more "forgiving"

Aftermarket support

Most companies that manufacture process equipment would rather sell new, but most are quite pleased to support their older equipment.

Not every company has the same business model. It is important to know your equipment and the parts supply chain.

The following are some areas of comparison that must be considered when deciding between new, refurbished or used equipment:

Aftermarket parts. This is a very-important consideration for maintenance and repair turnaround time. No matter if you are considering new or used equipment, you should contact the OEM to find out the availability of parts. It is especially important to be sure you can obtain parts when needed, especially if the OEM is located in another country. Trying to get parts for an overseas machine made 30 years ago, for example, may be a challenge. Is the company still in business? Where are their foreign offices? Some resourceful companies have recognized a gap in the supply chain and decided to manufacture parts for older domestic or foreign equipment. Once you find them, you may be in good shape.

Aftermarket technical support. With new equipment, the availability of good aftersale support is almost assured. But when purchasing used equipment, the OEM may or may not provide adequate technical support. Find out if drawings, manuals and parts lists are available. They may charge $500 to $1,000 for these documents, but it is a good investment to ensure you have the right information on hand.

Application assistance. There is no doubt that a new equipment manufacturer has a vested interest in guiding you toward the correct equipment for your application. Due to the nature of chemical processing, subtle changes in product characteristics can have significant effects on the process and the equipment, which is why process guarantees are very rare. It is in the best interest of the OEM to help you acquire equipment that will accommodate your process.

Mechanical warranty. Mechanical warranties are a certainty with new equipment, but their real purpose should not be overestimated. Warranties are not substitutes for proper operation or preventative maintenance and should not be construed as process guarantees. Mechanical warranties provide benefits especially during the initial startup period. If faults arise, they will likely occur during the initial warranty period.

Avoid surprises and disappointment by verifying the specifics of the warranties before purchasing.

Delivery timing. The delivery time for used equipment is typically just days, while new equipment will likely be months.

Design features. Within limits, new equipment can be outfitted with virtually every manner of control, CIP systems, quick access to internal parts, and other features to improve productivity and uptime. Used equipment is sold "as-is," so you will either need to find a good match or compromise on the features you would like to have. Refurbished equipment may present some opportunities for upgrades and modifications.

Price. New equipment is not expensive if you buy into Edward Deming's idea that you are purchasing *total* value. If you only consider price, then new equipment may appear to be more costly. LCC is blind to new versus used equipment, so let the risk data fall where they may.

Right to return. With new equipment, once you have placed the order, you are essentially committed to the equipment. Backing out after the initial deposit has been made will have some definite costs. If you buy refurbished equipment, you are also committed once a deposit is made and work is undertaken.

Most used equipment dealers will allow equipment returns within 10 to 30 days if it does not work as anticipated. All dealers differ, so it is important to ask specifically before making the purchase.

Concluding remarks

Understanding the lifecycle costs of one piece of equipment or an entire process requires examining not just the cost of the capital equipment, but also the operating, maintenance and decommissioning costs. The other major longterm cost is the cost of downtime compared to investments in training, preventative maintenance and spare parts. Lifecycle cost analysis can be done in a rudimentary fashion or it can employ complex what-if algorithms, but in either case, the benefits of taking a broader view of the factors that may impact the long-term cost of a process will benefit you and your company. ■

Edited by Scott Jenkins

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Author

Jeff Hoffmann is a vice president at Paul O. Abbe Co, (735 East Green Street, Bensonville, IL 60106; Phone: 630-258-4720; Email: jhoffmann@pauloabbe.com). Hoffmann has an educational background in chemistry and a M.S. in industrial and organizational psychology. During the past 20 years, Hoffmann has held sales, marketing and executive positions at several process equipment companies. He also holds six U.S. patents for various process equipment designs.

Getting the Most Out of Data Sheets

Data sheets should function as the central document to guide the procurement process

Mohammad Toghraei
Engrowth Training

For most engineering-procurement-construction (EPC) projects in the chemical process industries (CPI), the data sheets developed at the beginning of the process provide the "shopping lists" that guide the procurement group on the purchase of equipment, system packages, instruments and more. Data sheets should function as the central document, into which all final result of design or specification calculations will be transferred, to commence the procurement process.

During the operation of the facility, well-crafted data sheets will be used as key reference documents. They can also provide crucial information during debottleneck and retrofitting projects on existing plants.

There are usually five disciplines that deal with tangible goods (such as equipment or instruments) in an EPC project. They are the mechanical group, the instrumentation-and-control (I&C) group, the piping group, the electrical group and the civil group.

Another group — the process group — does not typically manage the purchasing of items. Rather, the process group is principally responsible for designs and specifications. They don't "own" any tangible goods (such as equipment or instruments) and thus, they usually don't manage the procurement process.

Each of these groups is generally the "owner" and "buyer" of certain items required by the project or facility. For example, the mechanical group is the owner and buyer (working through the procurement group) of equipment components. The I&C group is responsible for design and purchase of the instruments and control software. The electrical group is responsible for designing and buying electrical items such as electric motors. When it comes to piping, the piping group does not necessarily "design" the piping items per se, but this group is responsible for buying standard and off-the-shelf piping components. Typically, the piping group provides a list of available pipes, valves and fittings, and the design engineer selects the most suitable items from those piping-specification document.

For the piping items that are listed and specified in the piping-specification documents, there is no need to prepare separate data sheets for them. However, there may be some items that will be installed on or in the piping but that are not listed in the piping-specification documents. These include "specialty items," such as strainers, injection quills and more. These are items that are not typically standardized in the piping-specification document and thus must be described in a data sheet. As a result, the data sheet should be provided for all specialty items.

As noted, the process group is the only group that is not the owner (and buyer) of any tangible items. However, this group is often the first group that does the preliminary design of items required by almost all other disciplines, the process group is often responsible to start preparing data sheets for equipment components and systems, instruments, specialty items and even process-related civil items.

However, not all the data sheets start with the process group. For example, some purely mechanical items (such as gear boxes) might start with mechanical group.

Usually the data sheet for inline elements, such as sensors, control valves and switching valves, is prepared by the process group first. Then, the I&C group completes the data sheet by adding information that is required to make the purchase.

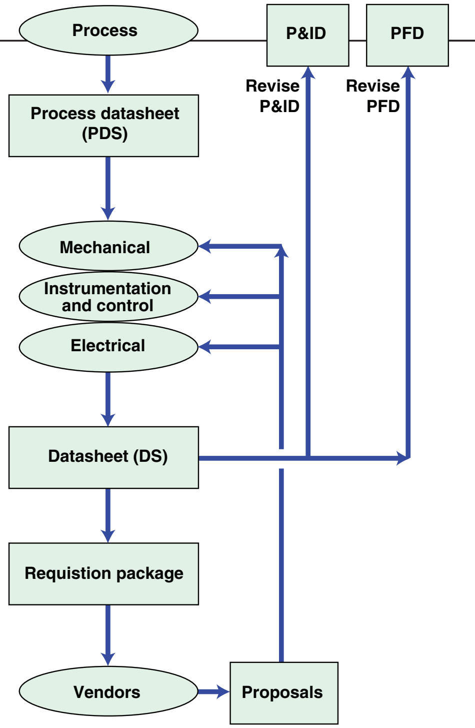


FIGURE 1. This flow chart shows how a given data sheet may work its way through the different disciplines. Eventually, completed data sheets will guide the discussion with vendors, and the data from the final revised data sheet will be used to update other key documents, such as the process flow diagram (PFD) and the P&ID.

However, the data sheet for the offline elements of control systems such as transmitters and indicators can be initiated by the I&C group, by using process data that was already provided by the process group for the relevant primary elements. For example, an I&C engineer can prepare the data sheet for a flow transmitter based on the information that was provided on the flowmeter data sheet.

Equipment data sheets

The amount of information on any given data sheet can vary greatly from a few sentences on information in a call-out box showing the equipment components in P&ID up to information in the equipment-specification document. The information in that datasheet should be more in-depth than the information in the call-out box but definitely more brief than the information in the equipment-specifi-

EQUIPMENT TYPES FOR WHICH STANDARD DATA SHEET TEMPLATES ARE AVAILABLE	
Equipment	**Industry standard**
Centrifugal pumps	API-610, ASME B73.1, B73.2
Controlled volume (PD) pumps	API-675
Heat exchangers, S&T	API-660
Centrifugal compressors	API-617
Steam turbines	API-611
Rotary pumps	API-676
Reciprocating pumps	API-674

cation document (which may be a few pages long).

Data sheets can be classified based on the level of detail that design engineers are willing to show on them, according to two types:

1. Black box (functional) data sheets
2. Conventional (detailed) data sheets

In *black box (functional) data sheets,* the design engineer basically defines what the feed is and what the required product will be. Additional data, such as the utility consumption table and possibly assigned footprint area could be added to black box data sheets, too. Using this type of data sheet, the vendor has the flexibility to select and design different types of systems that could meet the requirements of the client.

Conventional (detailed) data sheets are those that include all the detailed information that is needed for the vendor to design the requested equipment. These offer less room for vendor/manufacturer creativity.

Data sheet templates

There are generally two ways to develop data sheets. In the first method, the process group starts with the data sheet (specifically, a process data sheet, or PDS). This group does the work to create the first version of a data sheet, and then the individual disciplines amend and revise that data sheet to add relevant, discipline-specific information. The group then issues the final data sheet to the engineering discipline, which is responsible for the procurement activities (through the procurement group). For example, in preparing the data sheet for equipment, the mechanical group will issue the final (amended) version of the data sheet, which could then be named mechanical data sheet (MDS).

Figure 1 shows a non-inclusive flow chart of how a given data sheet may travel through the different disciplines. As shown, the data sheets will eventually be updated based on the communication and discussion with vendors, and the data from the final revision of the data sheet must ultimately be used to update other key documents, such as the process flow diagram (PFD) and the P&ID.

In the second method, an established data sheet can be used as a generic template, allowing all of the blank cells to be filled out by the different disciplines. The second method is more suitable for cases where the company is already fully aware of the detail of the equipment or package they plan to buy. In this method, there is no separate PDS or MDS and no interim data sheets.

For standard equipment such as pumps and heat exchangers, a variety of data sheet templates can be found in the respective standards. The Table shows a non-inclusive example of the types of data sheet templates that can be found in the industry standards.

For less popular or custom-made equipment, the primary template could be found in different technical books. For instance, Ref. [*1*] offers a good collection of equipment data sheets. If a package is to be bought, the design engineer should develop tailor-made data sheets.

Avoid poor practices

The process of preparing strong, relevant data sheets will be improved by avoiding the following poor practices:

1. *Using "TBD" ("to be determined") notations.* If the TBD convention is to be used as a place-holder until final details can be gathered, be sure to follow up to make sure the missing information is provided in suitable time.
2. *Using "by vendor" in places that the data should really be provided by the client or engineering company.* To be more specific, all of the boundary information (such as pressure, temperature and so on at the edge or border of vendor's scope of work) should be provided by the engineering company. For example, engineering company must

report the required pressure at the edge of the package boundary.

3. Failure to clarify definitions of key terms. The engineering company and vendor should clarify the definitions of critical terms, such as "normal, design, rated, maximum, design and rated capacities." In some companies, "rated" and "design" are two names for the same concept, and "maximum" doesn't necessarily mean the design parameter.

4. Failure to define potential material-compatibility and corrosion issues. There are two approaches for specifying materials of construction for specific equipment components and packages. Using the strict approach, the engineering company or client wants to have the equipment with a specific, stated material. In this approach, instead of reporting potentially corrosive materials that the components may be exposed to, the material of construction should be requested directly. For example, if the team wants to have equipment built from an acid-resistant material in "Region two of NACE 175," reporting the corrosive agents and their concentrations may leave the decision open to vendor to interpret the data and suggest sour or non-sour materials. If the design engineers intend to leave the material-selection decision on the vendor, they need to choose the second option, which reports corrosive or erosive species with their concentrations.

5. Using brand names instead of generic names for required equipment and packages. Brand names should be avoided as much as possible to ensure the fairest, most competitive bids from all vendors.

6. Risking errors by inserting information or data that should more appropriately come from other disciplines. Sometimes the boundaries between the disciplines are not very clear. In such cases, the test question should be "Am I completely competent to provide this number or information?" For example, in pump-related data sheets, specifying the rpm of the impeller is not generally the responsibility of the process group. However, if the pump will be handling oily water or water with fragile, suspended solids, the process engineer could have some specific mechanical requirements, such as maximum rpm or the clearance of the pump. It is better to cover these limitations in a note within the data sheet rather than in the main body of the data sheet, because process requirements are not the only criteria required to specify the rpm of the impeller.

7. Putting extra notes in note area. The use of notes should be avoided unless it is truly justifiable. Notes typically have several inherent issues. First, they are often overlooked. Second, they introduce the chance of being in conflict with the information in the main body of the data sheet. If one data sheet has too many notes in the note area, it suggests that the selected data sheet template was not suitable for the required equipment. The template should be designed in such a way that the data are mentioned in the main body of the data sheet, as much as possible.

8. Including too much information. Putting in information that is not related to manufacturing the equipment can be confusing for the vendor. The engineering company should be careful to put in just the most relevant information. For example, for a pump data sheet, the normal and maximum flowrate must be specified. However, for the pump to work in different services and flowrates, the engineering company might choose to put one representative condition (including flowrate and required head) in the pump data sheet. In such cases, the engineering company (not the vendor) is responsible to verify whether the proposed pump can handle all of the operating cases properly.

In some cases, the manufacturing company may be willing to work closely to cooperate with the engineering company if competing operating scenarios are complicated.

9. Erratic management of data sheet revisions. The procedure for revising the data sheet during the design and procurement process should be agreed to by all parties. The procedure could be more complicated if there are more than one data sheet for an equipment like process data sheet (PDS) and mechanical data sheet (MDS). All participants should agree on confusing issues ahead of time. For instance, if an MDS is developed based on a PDS and the process group changes a number in a design, should they go and reflect the changes directly in the MDS, or do they need to start from the PDS? Similarly, if the vendor (with the agreement of the client) decided to change a number in the equipment design, should it be reflected only on MDS, or on both MDS and PDS. All participants should agree on these issues ahead of time.

10. Inconsistency with other documents. The information on the data sheet should be consistent with other documents that have similar content, such as P&ID or LDT. For example, a line-designation table (LDT) — which is basically a list of all pipes in the plant — specifies the design temperature and design pressure of the pipes. These parameters on the data sheet should be matched with the parameters on the LDT. However, "matching" doesn't mean the numbers should be identical. For instance, a designer can decide to put a lower design temperature and pressure (on the instrument data sheet) for a sensor in a pipe with higher design temperature and pressure. This is acceptable as long as the residual risk of this action is within tolerable range of the client.

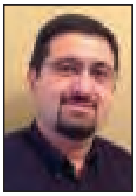
Considering the above practical points during the preparation and issuing the data sheets will minimize the debate with vendors and decrease the number of frustrating "cost-adders" during the project. ■

Edited by Suzanne Shelley

Reference

1. James, R.,and W. Roy Penney, James R. Fair, "Chemical Process Equipment: Selection and Design," 2nd Ed., Gulf Professional Publishing, 2009.

Author



Mohammad Toghraei, P.Eng., is an instructor and consultant with Engrowth Training (Phone: 403-808-8264; Email: engedu.ca), based in Calgary, Alta. He has more than 20 years of experience in the field of industrial water treatment. His primary expertise is in the treatment of wastewater from oil and petrochemical complexes. He holds a B.Sc. in chemical engineering from Isfahan University of Technology, and an M.Sc. in environmental engineering from Tehran University, both in Iran. He is also a member of APEGA (the Assn. of Professional Engineers and Geoscientists of Alberta).

Rotary Valves in Pneumatic Conveying Systems

Because of their wide application in pneumatic conveying systems, it is important to understand how rotary valves are designed and used

Amrit Agarwal
Pneumatic Conveying Consulting

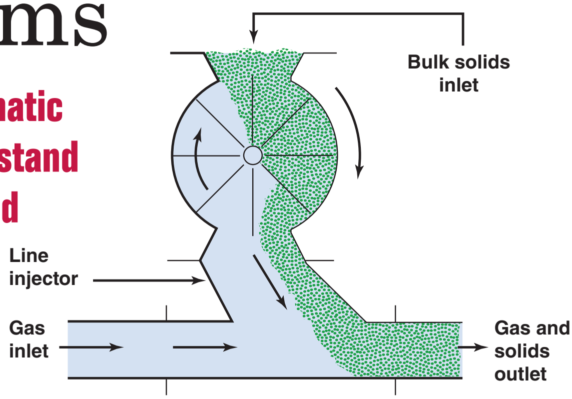


FIGURE 1. In a drop-through valve, the solids inlet and solids outlet are typically the same size and are vertically aligned. As the rotor turns, the empty rotor pockets are filled by solids that flow vertically down from a hopper located above the valve

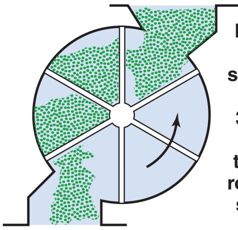


FIGURE 2. In a side-entry rotary valve, the solids inlet and solids outlet are typically offset from the vertical flow line by 30–45 degrees. This allows the upcoming empty rotor pocket to be filled only partially as the rotor turns, helping to minimize shearing and jamming of solid particles during operation

Rotary valves are used almost universally in pneumatic conveying systems. They serve three main functions: 1) to provide a pressure-seal (airlock) between two adjacent processes, 2) to provide solids metering (feeding) and 3) to provide a combination of solids metering and a pressure-seal for feeding solids into a pneumatic conveying system.

Rotary valves are common devices for feeding solids into a pneumatic conveying pipeline, and they function in different ways in different circumstances. For instance, rotary valves can function as follows:

- As an airlock at locations where an air-seal is needed, such as at the end of a pneumatic conveying system where the conveyed solids are discharged from a receiving vessel into a storage hopper, bin or silo
- As a feeder when they are used to discharge a fixed or a variable volumetric flow of solids from an upstream process to a downstream process
- As a combination airlock and a feeder when they meter solids into a pneumatic conveying pipeline

Key aspects of how rotary valves are designed and used are discussed below.

Types of rotary valves. Rotary valves are generally made in the following three varieties:

1. Drop-through type
2. Off-set or side-entry type
3. Blow-through type

In a *drop-through valve* (Figure 1), the solids inlet and outlet are vertically inline and are generally of the same size. When the rotor starts to turn, the empty rotor pockets are filled by the solids flowing vertically down from a hopper above the valve. These valves can have square, rectangular, or round inlets and outlets; the square shape is more common because it provides a larger opening area compared to a round-shaped opening.

In a *side-entry valve* (Figure 2), the solids inlet is offset from the vertical, solids-gravity-flow line by 30 deg. This offset allows the upcoming empty rotor pocket to fill only partially when the rotor turns past the valve inlet. This partial filling minimizes shearing of the solid particles that sometimes get trapped between the rotor and the valve housing. Partial filling also prevents jamming or seizing of the rotor by solid particles that sometimes becometrapped between the rotor and the valve housing. The volumetric fill efficiency of the empty pocket depends on the solid's flow properties, but it is generally about 60%. These valves should have an adjustable slide plate in their inlet section to allow for the increase or decrease of pocket filling.

Blow-though valves are similar to drop-through valves except that they are installed directly in the conveying line without any intermediate device. In this design, the conveying gas enters from one end of the rotary valve, blows through the emptying rotor pocket, and carries the solids to the opposite end of the rotary valve and directly into the conveying line. These valves are used for materials that are sticky and have difficulty in flowing out from the rotor pocket.

Rotary valve construction. Rotary valves have three main components: A cylindrical body with both ends closed, a horizontal rotor that rotates inside this body, and a drivetrain that drives the rotor. These components are described below:

Rotary valve body. The valve body is a horizontal cylinder with a top inlet and a bottom outlet, and with vertical plates to close both sides of the cylinder. The body is generally cast from a metal such as cast iron, carbon steel, stainless steel or aluminum, although other materials are used for special applications, such as very high temperatures or highly abrasive solids. All internal surfaces of the cylindrical body are made smooth by polishing or chrome-plating because smooth surfaces are needed to maintain the required tight clearances between the valve body and the rotor. A surface finish of 2B is desirable.

The valve rotor is of welded-steel or stainless-steel construction with eight or more pockets. Its horizontal shaft is also steel or stainless steel.

The entire valve is designed to withstand the maximum and minimum pressures and temperatures to which the valve will be exposed. These include both process and ambient conditions.

To maintain the required clearances, in locations where the valve is exposed to extremely low temperatures (such as –40°F), the valve body is jacketed, heated and insulated. The heating medium is a heat-transfer fluid that is circulated throughout the body to maintain a constant and uniform temperature. Alternatively, the valves can be installed inside heated enclosures that are provided with easy access for the valve's inspection and maintenance.

In locations where temperatures are not extreme, electrically heated blankets placed over the valve body can be used to maintain a uniform body temperature.

The valve bottom may have an open or closed space between the rotor and the valve body. As shown in Figure 3, open bottoms allow solids that may have entered the clearance between the rotor ends and the valve body to drop out. *Open-bottom rotary valves* are unsuitable for feeding solids into positive-pressure-type conveying systems, because they allow the conveying air to flow upward into the clearances, thereby increasing the potential for conveying air leakage. These valves can be used in vacuum-type conveying systems such as airlocks, or as a feeder. In most pneumatic conveying applications, *closed-bottom rotary valves*, such as that shown in Figure 4, are more commonly used because they provide a better air seal between the rotor edges and the valve body.

For feeding coarse particles such as plastic pellets, drop-through rotary valves are provided with a well-configured inlet plow in their inlet section. This plow prevents solids from entering the clearance between the rotor and the valve housing, thereby preventing the resulting jamming or seizing of the rotor. The plow is V-shaped, is cast or welded into the downstream side of the rotary valve inlet, and directs the solids flow into the rotor pocket.

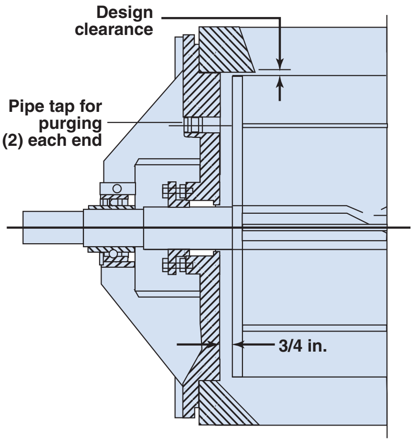


FIGURE 3. In an open-bottom rotary valve, solids that may have entered the clearance between the rotor ends and valve body are allowed to drop out. This option is not viable for feeding solids into positive-pressure conveying systems, but they are suitable for vacuum-type conveying systems, such as airlocks

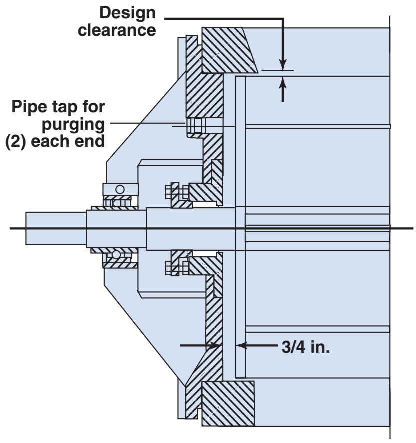


FIGURE 4. Closed-bottom rotary valves are widely used in pneumatic conveying applications because they provide a good air seal between the rotor edges and the valve body

Rotors. Rotors are of welded construction with rectangular-shaped blades that are welded to a shaft. Blades are evenly spaced around the rotor, forming triangular pockets. The bottom of the pockets can be flat or curved, depending on whether the solids are free-flowing or sticky.

The number of blades is at least eight for any size rotary valve. Large size valves, such as thouse with 4 ft^3/rev. capacity or larger, can have have 10 or 12 blades.

Blade tips are generally hardened with stellite or tungsten carbide to reduce their wear. When handling coarse solids, such as plastic pellets, tips are generally relieved at a 45-deg angle on their trailing edge to prevent clipping of the pellets and the resulting binding of the rotor inside the valve housing.

The two ends of the rotor can be open or closed. In open-end rotors, rotor pockets are fully open on both ends. In closed-end rotors, rotor pockets are fully closed by full-size plates that are welded at each end. Blades are welded to the shaft and also to the two end-plates, thereby providing strength and rigidity to the rotor. Closed-end rotors are, therefore, more rigid and sturdy, and are less prone to flexing and bending under high differential pressures than open-ended rotors. They are used for a large variety of materials. Open-ended rotors cost less but are more susceptible to bending and rubbing with the internal surface of the valve housing, resulting in its wear and erosion.

In closed-end rotors, the clearance space between the end plates and the valve housing is generally about ½ to ¾ in.

Rotary valve drive. Rotary valves are generally driven by a gear-head motor, instead of by a separate motor and a gear box, because this method is more economical. The gear-head motor reduces the output speed to about 30 rpm. From this motor, the rotary valve rotor is driven by chain and sprockets to arrive at the valve speed that is needed. This motor can be installed either at right angles to, or parallel to, the rotary valve. Parallel installation with a chain-and-sprocket drive is preferable because valve speed can be changed easily by changing sprockets. Right-angle installation is more difficult because it requires changing of worm gears to change the speed.

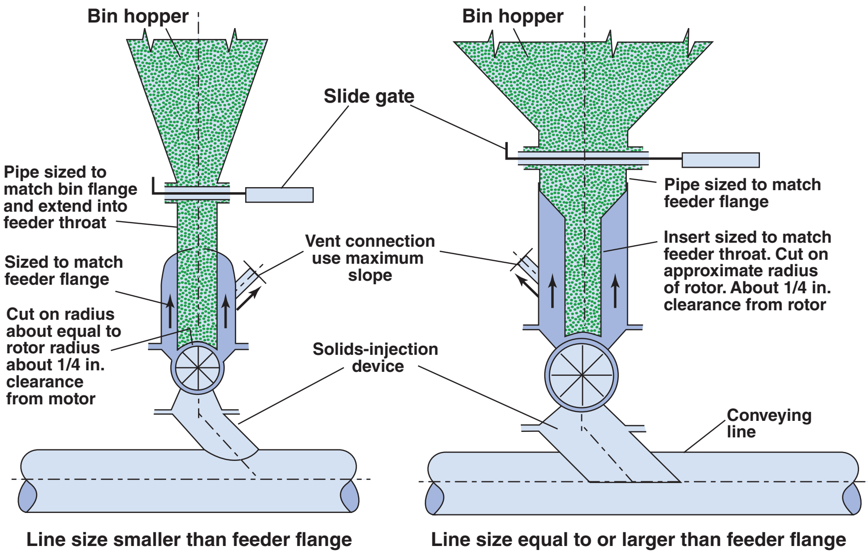


FIGURE 5. This installation shows a rotary valve venting system for a dilute-phase conveying system, to evacuate leakage between the rotor and valve housing. The solids-feed chute extends into the rotary valve, as shown. The feed chute's bottom matches the outer contour of the rotor with a space of 1/8–1/4 in. between it and the rotor. A leakage gas vent chamber is installed above the rotary valve. The annulus between the feed chute and this vent chamber is 2-in. minimum. Leakage gas flows into ths annulus and exits via a vent nozzle to a dust collector and exhaust fan

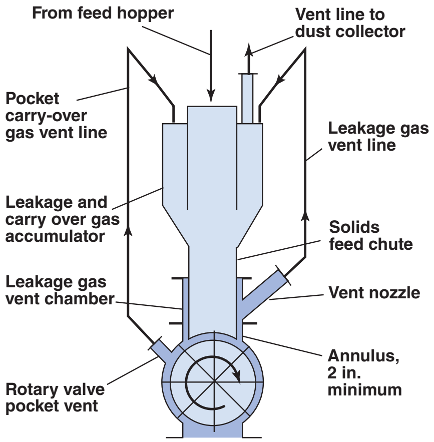


FIGURE 6. Air leakage between the rotor and the valve housing must be vented so that it does not interfere with the flow of incoming solids. In this venting installation, for a dense-phase conveying system, a solids-feed chute extends into the rotary valve, as shown. The feed chute's bottom matches the outer contour of the rotor with a space of 1/8 in. between it and the rotor. A leakage gas-vent chamber is installed above the rotary valve. The annular space between the feed chute and this vent chamber is 2 in. minimum. Leakage gas flows into this annular space and exits via a vent nozzle to the top of the leakage gas and pocket carryover gas accumulator. Carryover gas from the rotor pocket and body vent is also vented to this accumulator

The rotary valve shaft extends beyond the side plates of the valve housing using outboard, spherical-roller, dust-sealed-type bearings between the shaft and the housing. For shaft packing, a long-wearing material such as Teflon with Neoprene gaskets is typically used. The normal speed range of rotary valves is 15 to 22 rpm. For rotary valve sizing, the typical speed used is 16 rpm.

Rotary valves used in continuous production operations are provided with a zero-speed motion switch that is installed on the driven shaft to detect chain breakage and the resulting valve stoppage.

Rotary valve pressure rating. For pneumatic conveying systems, rotary valves are designed so that the rotor can withstand the maximum pressure differential across the valve's inlet and outlet. In most cases, this pressure is 15 psi for dilute-phase conveying systems. However, instead of using 15 psi, the differential pressure rating should be based on the actual design pressure of the conveying system.

Deflection of the rotor at the midpoint of its axis due to this differential pressure drop must not exceed 0.001 in.

The internal vacuum or pressure rating of the rotary valve housing should be 10% higher than the maximum operating vacuum or pressure to which the housing will be exposed. Most standard rotary valves have a 150-psig housing design pressure.

Rotary valve clearances. Clearances between the rotor and the rotary valve body must be as small as possible, and they must be concentric. Typically, circumferential clearances are between 0.004 and 0.008 in., and end-clearances are 0.006 to 0.0010 in. To minimize conveying gas leakage, the design clearances should be the lower value of these ranges.

Binding or seizing of the rotor inside the housing should be prevented by maintaining these minimum clearances at the highest and lowest operating temperatures of the incoming solids and of the ambient conditions.

The rotary-valve vendor should perform tests to measure the clearances, and the air leakage as a function of rotary valve speed, before the valve is accepted for use. This test should be run under the actual operating conditions, such as ambient and process temperatures and pressures. Hot air may be needed to heat the valve when it is operated under temperatures higher than the ambient.

Leakage-venting methods. In pressure-type conveying systems, pressurized conveying air that fills the returning empty rotor pockets is carried over to the inlet side of the rotary valve. To prevent this air from interfering with the flow of incoming solids, this air is vented out from the valve before it reaches the valve inlet. This is done by providing a vent port on the return side of the valve body. To prevent increasing air leakage, this vent port is located so that there are at least two rotor pockets between the valve bottom and the vent port. The vent port size should be large enough

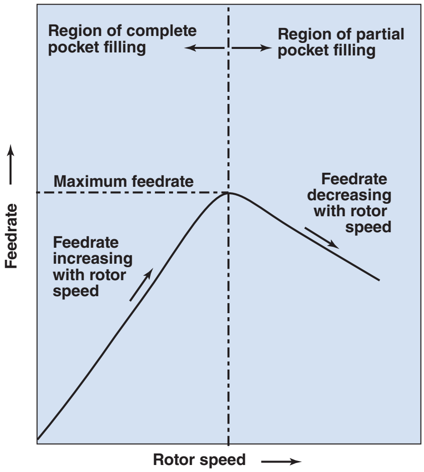


FIGURE 7. Rotor speed impacts the feed rate of a rotary valve, as shown here. Theoretically, the solids-throughput rate should increase linearly with valve speed, althought as shown here, the feed rate decreases after reaching a maximum rate over a typical speed range of 15–22 rpm

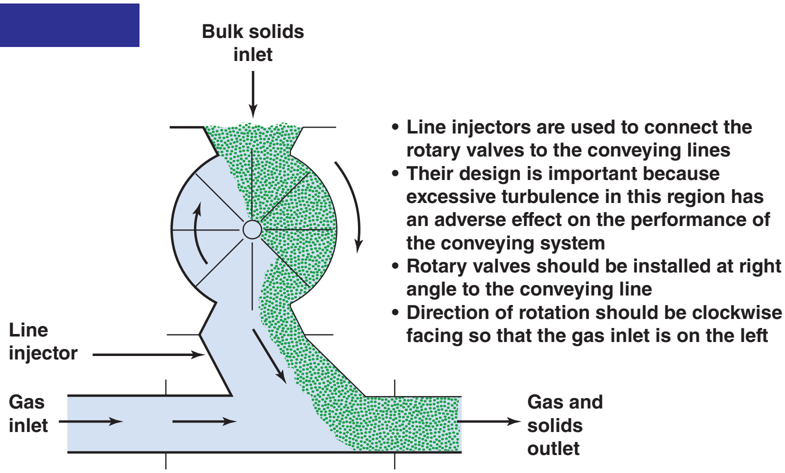


FIGURE 8. When the rotary valve is used to feed solids into a conveying line, the rotary valve and the line injector below it are perpendicular to the conveying line.

to completely vent out the entire air volume contained in the rotor pocket. For large valves, a rectangular-shaped vent port about one-half the length of the pocket width is recommended.

When conveying powders or fine granular materials, air that is vented out from this vent port may contain significant amounts of these solids. To prevent their loss, these materials should be fed back into the rotary valve using a properly designed vent hopper installed at the rotary valve inlet.

In addition to the carryover air described above, there is also air leakage from the circumferential and end clearances between the rotor and the valve housing. These leakages should be vented out so that they do not interfere with the flow of incoming solids. This is done by using a specially designed insert that extends from the inlet of the valve up to its rotor tips. This insert provides an annular path between the insert and the valve body to vent out the leakage air. This insert should extend from the inlet of the rotary valve up to the rotor surface with a gap of about 1/8 in. between the rotor and the insert. Details of this venting method are shown in Figure 5 for dilute phase systems and in Figure 6 for dense-phase systems.

Leakage-calculation methods. Complete information on rotary valve leakage calculations can be found in Ref. [1].

The flowrate of clearance leakage can be calculated using Equation 1:

$$Q = C \times A \times \left[(2g)(dp)\right]^{1/2} \qquad (1)$$

Q = Leakage flowrate, ft^3/s
C = Orifice constant = 0.5
A = Clearance area, ft^2
g = Gravitational constant, 32.2 ft/s^2
dp = Pressure differential across the rotor, lb/in.^{2}

As shown in Equation 1, leakage flow is directly proportional to the clearances between the rotor and the valve housing. For medium-sized rotary valves, this clearance is 0.004–0.006 in., or 0.10–0.15 mm.

The flowrate of carryover air can be calculated by using the following relationship:

Carryover air flowrate (ft^3/s) equals Rotor displacement (ft^3/rev) multiplied by rotor speed (rpm/60)

Rotary valve capacity. Figure 7 shows the solids-throughput rate attainable in a rotary valve versus rotor speed. Theoretically, the solids throughput should increase linearly with the valve speed — that is, with the number of valve rotations.

In practice, however, throughput increases only up to a maximum value, and then starts to reduce when the speed is further increased. This happens because while falling from the rotor pocket to the valve bottom, solids face both gravitational and centrifugal forces. At high rotor speeds, because of centrifugal forces, some of the solids remain in the emptying pocket. This results in reduced fresh material that can flow into the valve inlet, thus reducing the fill efficiency of the valve.

The capacity of a rotary valve (CFR) is calculated using Equation 2. It is expressed as volumetric flow per revolution of the rotary valve (ft^3/rev of solids flow):

$$CFR = \frac{W}{\delta_B \times N \times E \times 60} \qquad (2)$$

where:

CFR = Capacity of a rotary valve, ft^3/rev
W = Solids flowrate, lb/h
δ_B = Solids bulk density, lb/ft^3
N = Valve speed, rpm
E = Pocket-fill efficiency

Pocket-fill efficiency. Shown below are typical pocket fill efficiencies for different types of rotary valves:

- Side-entry rotary valve: 40– 60%
- Drop-through, flood-fed valve: 60–80%
- Drop-hrough, flood-fed valve with body vent and leakage-air inlet insert: 90–95%

In general, the following factors provide better fill efficiencies:

- Lower valve speeds
- Lower ΔP across the valve
- Proper venting of the leakage gases from the rotary valve

Rotary valve installation. Rotary

valves that are used to feed solids into a conveying line are installed such that the rotary valve and the line injector below it are perpendicular to the conveying line (Figure 8). A line injector is used to connect the rotary valve to the conveying line. Its design is important because excessive turbulence in this region has an adverse effect on the performance of the conveying system.

In pressure-type conveying systems, any intermediate spool pieces between the rotary valve and the line injector, or between the line injector and the conveying line, should not be used because the resulting air turbulence can adversely affect the flow of solids into the conveying line.

The direction of rotation of the rotary valve should be clockwise when facing the valve, such that the conveying air enters the conveying line from the valve's left side.

Rotary valves in dense-phase pneumatic conveying. Presently, rotary valves used in dense-phase pneumatic conveying are designed to withstand differential pressures up to 6 bars and maximum solids feed rates of about 5,000 ft^3/h. High circumferential clearance leakage that occurs due to these high pressures is minimized by increasing the number of rotor blades. Some good designs have as many as 24 blades.

Rotor-end leakage is prevented by using a specially designed, gas-tight seal between the rotor and valve body. A well-designed venting system to properly vent out the clearance leakage air and the rotor carry-over air is a necessity for these high-pressure-drop rotary valves.

Rotary valves with special features. Rotary valves are made with special design features for applications such as food grade installations, those requiring quick and easy access for cleaning, those handling corrosive, abrasive or sticky materials, those handling very high or very low solids or ambient temperatures, but the basic design principles described above still apply to these designs. ■

Edited by Suzanne Shelley

Reference

1. Agarwal, Amrit, "Improving Rotary Valve Performance," *Chem. Eng.*, March 2005, pp. 29–33.

Author

Amrit Agarwal is a consulting engineer with Pneumatic Conveying Consulting (7 Carriage Rd., Charleston, WV 25314; Email: polypcc@aol.com). He retired from The Dow Chemical Co. in 2002 where he worked as a resident pneumatic conveying and solids-handling specialist. Agarwal has more than 40 years of design, construction, operating and troubleshooting experience in pneumatic conveying and bulk-solids-handling processes. He holds an M.S. in mechanical engineering from the University of Wisconsin, Madison – Wisconsin, and an MBA from Marshall University (Huntington, West Va.). He has written a large number of articles and given classes on pneumatic conveying and bulk solids handling.

Fractionation Column

Selling new technologies

Mike Resetarits is the technical director at Fractionation Research, Inc. (FRI; Stillwater, Okla.; www.fri.org), a distillation research consortium. Each month, Mike shares his first-hand experience with *CE* readers

During my youth, as a mass- and heat-transfer R&D manager, there were 12 occasions when new technologies were sold for the very first time. One or two of those technologies might have been considered "breakthroughs." The others were very significant twists on well-established technologies. Of the 12 first-of-a-kinds, 11 were sold to companies outside of the U.S. More on that later.

One new technology was a high-performance distillation tray that was first offered to an Austrian company, OMV, for use in their Schwechat refinery. The name "Resetarits" is of Austrian origin, and I was the co-inventor of the tray, along with Mike Lockett, and so, it made perfect business sense for me to go to Vienna, to try to talk OMV engineers into becoming "the first."

I flew into Vienna airport, landing at about 5 p.m. I carried my luggage across the street to an airport hotel. The lobby was extremely crowded, but I was lucky because there was nobody at the check-in counter. My German-language capabilities were weak. I simply handed the hotel desk attendant my credit card and open passport. She gasped disappointedly and asked, "Your name is Michael Resetarits?" I answered, "Well, yes, miss." She said, "In Austria now there is a famous piano player who tells political jokes in between songs. All of these people in the lobby are from the first shift of the hotel staff. They have been waiting one hour to get the autograph of Michael Resetarits." After stuttering for several seconds I said, "I do tell jokes; I do not play piano; I have never been more disappointed to be me." She checked me in and I headed toward my room. As I awaited the arrival of the elevator, the desk attendant informed the lobby gang that there are two people with that same name and that the wrong one just checked in. The lobby gang did not appear to be disappointed — "angry" is a better word. I hid in my hotel room all night watching CNN on the television.

So anyway, of 12 first-of-a-kind technologies, 11 were not sold to U.S. companies. They were sold, instead to European, Canadian, Korean and Chinese companies. Why? I am afraid that I have no answers. Are U.S. companies more risk averse? Maybe. Are non-U.S. engineers more portable, or in other words, do they make decisions and judgments for a couple of years and then they move off to other job assignments? Maybe. Are non-U.S. plant managers more accepting of capacity and efficiency shortfalls. Maybe. Are non-U.S. engineers better at assessing and accepting shortfall conditions? Maybe.

I have four pieces of advice for a salesperson or an R&D engineer who is attempting to sell a new technology. First, explain as concisely and clearly as possible your laboratory and pilot plant results. Second, explain the technology's benefits. Third, evaluate and explain what will and will not happen if a shortfall occurs. Fourth, change your last name to that of the most popular jokester piano player of the country where you will be selling your technology — and learn to play piano. ■

Mike Resetarits

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Hovione (Loures, Portugal), a developer of active pharmaceutical ingredients and drug-product intermediates, appoints *Justin Hughey*, to lead the particle-design sciences team at its New Jersey site.

Bayer MaterialScience LLC (Pittsburgh, Pa.) names *Christine Bryant* as head of commercial operations for its coatings, adhesives and specialties business unit for the NAFTA region.

Douglas Joy becomes general manager of **Heraeus Sensor Technology USA** (North Brunswick, N.J.), a division of **Heraeus**, a precious metals and technology company headquartered in Hanau, Germany.

Akro-Mils (Akron, Ohio), a provider of plastic and metal storage, organization and transport products, names *Mike Iafigliola* new product development manager.

M. Metin Gerceker becomes managing director of **Zimmermann & Jansen (Z&J) Technologies GmbH** (Düren, Germany), a maker of flow-control solutions for delayed coker, iron and steel blast furnaces and turbine units.

Polyolefins maker **Borealis AG** (Vienna, Austria), names *Gilles Rochas* vice president, energy and infrastructure, for the application segment.

Greene's Energy Group (Houston), a provider of testing and specialty services, promotes *Mark Yuille* to CFO of its testing and services business unit. ■

Suzanne Shelley

BUSINESS NEWS

PLANT WATCH

Uhde Inventa-Fischer to build commercial-scale Nofia plant
June 12, 2013 — Uhde Inventa-Fischer AG (Berlin, Germany and Domat/Ems, Switzerland; www.uhde-inventa-fischer.com) has won a contract to build the world's first commercial-scale plant for production of Nofia, a flame retardant polymer, for the Belgian subsidiary of FRX Polymers, Inc. (Chelmsford, Mass.; www.frxpolymers.com). The plant will be located in Antwerp, Belgium. Uhde Inventa-Fischer's scope of services will include basic and detailed engineering, supply of equipment, and construction of the plant. The civil engineering will be carried out by ThyssenKrupp Uhde GmbH (Dortmund, Germany; www.uhde.eu).

Siemens to supply wet-air-oxidation system to Qatar
June 10, 2013 — Siemens Energy (Erlangen, Germany; www.siemens.com/energy) will supply a wet-air-oxidation (WAO) treatment system as part of an ethylene plant expansion for Qatar Petrochemical Co. (QAPCO). The WAO system will be part of QAPCO's facility in Mesaieed Industrial City, Qatar. The facility is expected to go operational in December 2013. QAPCO is expanding its ethylene-cracking unit from 720,000 ton/yr to 900,000 ton/yr. The Siemens scope includes a Zimpro WAO system, as well as a complete power- management system.

Linde announces plans for ASU and gasification train in Texas
May 31, 2013 — Linde North America (Murray Hill, N.J.; www.lindeus.com) will invest more than $200 million to build a large air separation unit (ASU), a new gasification train, and supporting equipment and facilities in La Porte, Tex. The plants are scheduled to come on-stream in the first quarter of 2015. The ASU will be the largest operated by Linde in the U.S. The O_2 and N_2 produced by the ASU will supply the gasification assets at the La Porte site.

Toyo's Brazil affiliate awarded contract for hydrogen production facilities
May 29, 2013 — Toyo-Setal Empreendimentos Ltda. (TSE), a Brazilian joint venture (JV) capitalized by Toyo Engineering Corp. (Chiba, Japan; www.toyo-eng.co.jp), has been awarded a contract from Petróleo Brasileiro S.A. (Petrobras) for the construction of hydrogen production facilities (250,000 Nm^3/h) to be installed in the Complexo Petroquímico do Rio de Janeiro (Comperj) now under construction in Itaboraí, Rio de Janeiro. The scope of work is for detailed design, procurement of equipment and materials, installation and commissioning support. The project is scheduled for completion in mid-2016. Toyo is now constructing utility facilities (water treatment and electricity generation) for the complex.

Linde to build large ammonia plant in Russia
May 28, 2013 — The Linde Group (Munich, Germany; www.linde.com) has formed a JV with JSC KuibyshevAzot to build and operate a large ammonia plant at the Togliatti site in Russia's Samara region. Estimated investment for the deal is €275 million, giving both companies an equal stake in the new JV, called Linde Nitrogen Togliatti. The Engineering Division of The Linde Group will construct the new on-site plant, which will have a production capacity of 1,340 metric tons (m.t.) per day of ammonia. Construction is scheduled for completion in 2016.

Outotec to design and deliver concentrator to Russian Copper
May 22, 2013 — Outotec Oyj (Espoo, Finland; www.outotec.com) will design and deliver a new copper concentrator for Russian Cooper Co.'s Tominsky project in Russia's Chelyabinsk region. The concentrator will treat 17 million m.t./yr of ore and produce 63,000 m.t./yr copper in concentrate. The total value of the deal exceeds €50 million. Scheduled for 2014, Outotec's delivery for the project includes basic and detailed engineering of the concentrating process, proprietary and key equipment, as well as installation and commissioning supervision services, with production of concentrate beginning by late 2015.

Lanxess opens first production facility for high-performance bladders in Brazil
May 13, 2013 — Rhein Chemie, a wholly owned subsidiary of Lanxess AG (Leverkusen, Germany: www.lanxess.com), has opened a new facility in Porto Feliz, Brazil for high-performance bladders, which are used in the production of tires. It has an annual capacity of about 170,000 bladders. In 2014, a new facility to manufacture pre-dispersed polymer-bound rubber additives will be added. Altogether, Lanxess is investing €10 million and creating around 60 new jobs.

MERGERS AND ACQUISITIONS

Air Liquide to acquire electronic materials manufacturer Voltaix, Inc.
June 12, 2013 — Air Liquide (Paris, France; www.airliquide.com) has signed an agreement to acquire Voltaix Inc., a U.S. based electronics materials company. The acquisition is expected to close later this summer, pending applicable regulatory approvals. Voltaix has 185 employees.

BASF New Business acquires Deutsche Nanoschicht
June 6, 2013 — BASF New Business GmbH (www.basf-new-business.com) has acquired all shares of the technology company Deutsche Nanoschicht GmbH (www.d-nano.com). Deutsche Nanoschicht produces thin films for manufacture of high-temperature superconductors. BASF New Business GmbH is a wholly owned subsidiary of BASF SE.

Foster Wheeler acquires Mexican engineering company
June 4, 2013 — Foster Wheeler AG (Zug, Switzerland; www.fwc.com) has acquired NorthAm Engineering S.A. DE CV, a privately held engineering and project management company, offering services in upstream, offshore, downstream and power projects. Headquartered in Monterrey, Mexico, the company has approximately 400 employees.

Air Products acquires EPCO Carbon Dioxide Products, Inc.
June 3, 2013 — Air Products (Lehigh Valley, Pa.; www.airproducts.com) has acquired EPCO Carbon Dioxide Products, Inc., a privately held producer and marketer of liquid carbon dioxide The acquisition also includes Louisiana Leasing, Ltd. of Ill., an affiliated company that owns liquid CO_2 distribution assets that are solely leased to EPCO. The purchase price has not been disclosed.

Ineos Barex AG to acquire Mitsui's polyacrylonitriles business
May 28, 2013 — Ineos Barex AG (Rolle, Switzerland; www.ineosbarex.com) has signed a binding agreement to acquire the polyacrylonitriles (PAN) business from Mitsui Chemicals Inc. The value of the transaction was not disclosed. The deal is expected to reach completion by August 2013, at which time Ineos will assume responsibility for sales and marketing functions. ■

Mary Page Bailey

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Heat exchangers & tanks	626.2	624.2	686.9
Process machinery	656.5	651.1	680.7
Pipe, valves & fittings	875.6	879.8	935.7
Process instruments	413.3	414.3	430.8
Pumps & compressors	924.5	920.4	921.8
Electrical equipment	512.6	514.4	514.9
Structural supports & misc	746.8	741.1	774.2
Construction labor	319.8	319.2	320.7
Buildings	536.5	534.4	527.1
Engineering & supervision	328.1	326.4	328.4

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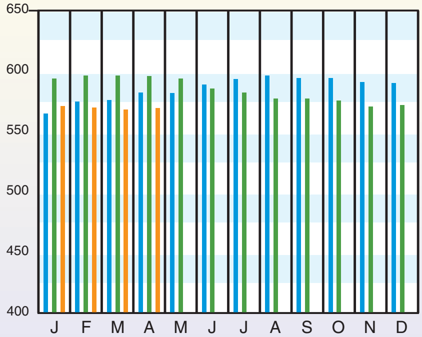
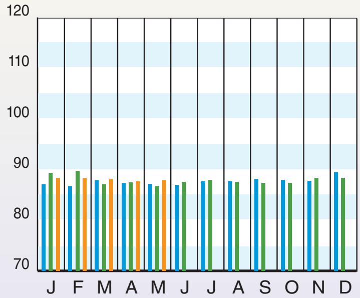
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6



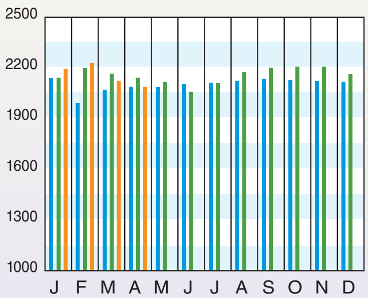
CURRENT BUSINESS INDICATORS

	LATEST		PREVIOUS				YEAR AGO	
CPI output index (2007 = 100)	May.'13	= 87.8	Apr.'13	= 87.6	Mar.'13	= 88.0	May'12	= 86.7
CPI value of output, $ billions	Apr.'13	= 2,089.2	Mar.'13	= 2,126.0	Feb.'13	= 2,228.4	Apr.'12	= 2,142.5
CPI operating rate, %	May.'13	= 74.1	Apr.'13	= 74.1	Mar.'13	= 74.5	May'12	= 74.2
Producer prices, industrial chemicals (1982 = 100)	May.'13	= 301.7	Apr.'13	= 308.7	Mar.'13	= 313.5	May'12	= 321.2
Industrial Production in Manufacturing (2007=100)	May.'13	= 95.3	Apr.'13	= 95.2	Mar.'13	= 95.5	May'12	= 93.7
Hourly earnings index, chemical & allied products (1992 = 100)	May.'13	= 156.2	Apr.'13	= 154.6	Mar.'13	= 154.6	May'12	= 157.1
Productivity index, chemicals & allied products (1992 = 100)	May.'13	= 104.8	Apr.'13	= 104.4	Mar.'13	= 104.7	May'12	= 106.0

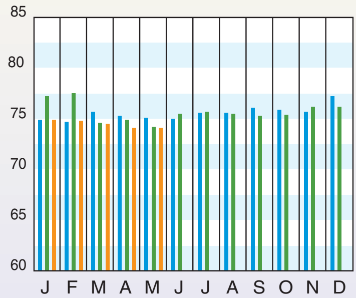
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

CURRENT TRENDS

Preliminary data for the April 2013 *CE* Plant Cost Index (CEPCI; top; the most recent available) indicate that the composite index increased by 0.2% compared to the final March value, reversing three consecutive decreases in the months prior. The higher numbers included increases in a number of subindices, such as process machinery, pumps & compressors and heat exchangers & tanks. The April 2013 preliminary PCI index value stands at 4.4% lower than the corresponding final PCI value from April 2012. Meanwhile, the latest Current Business Indicators from IHS Global Insight (middle) moved in both directions, with CPI output index inching higher while CPI value of output decreased slightly. ■