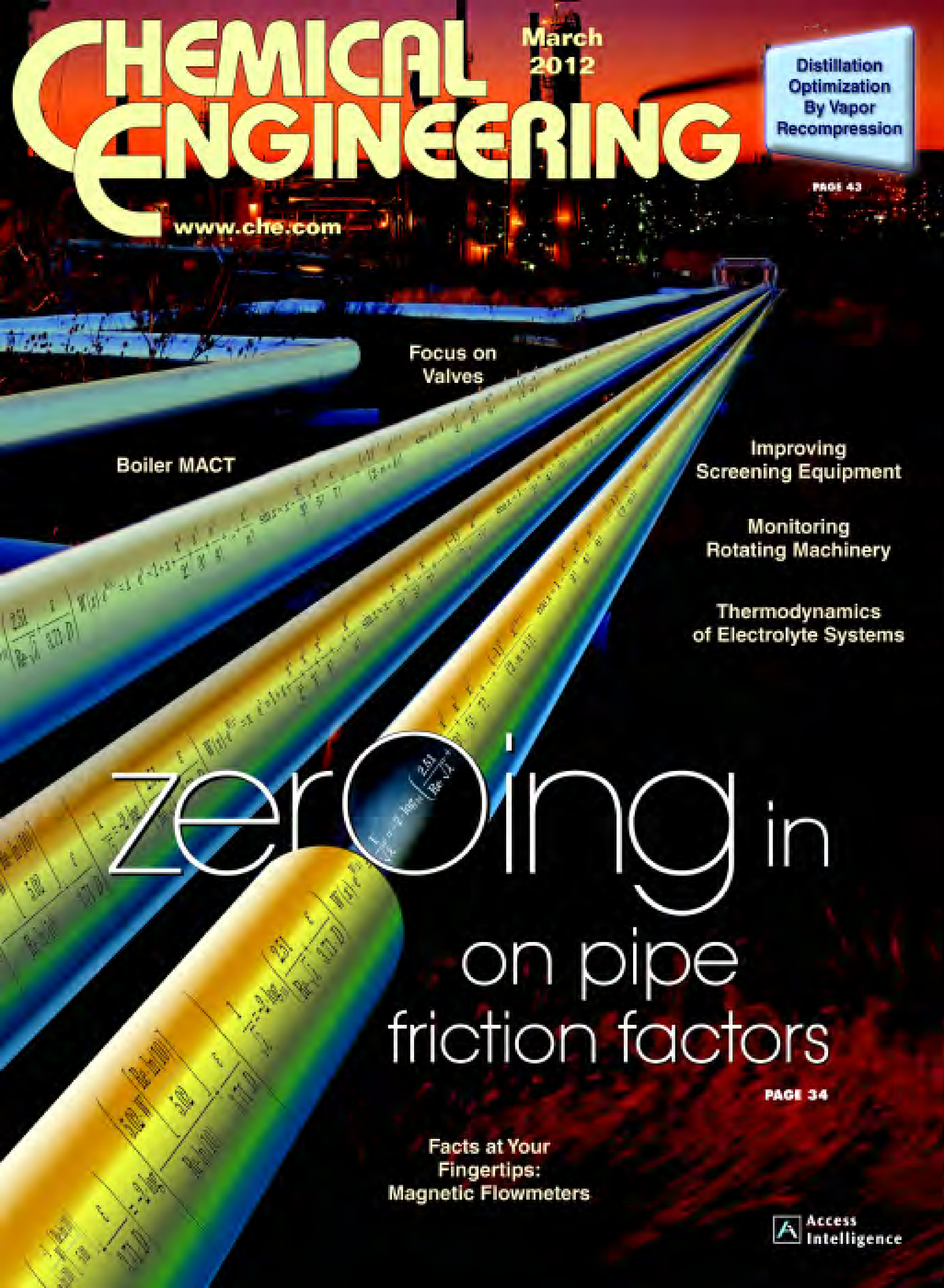
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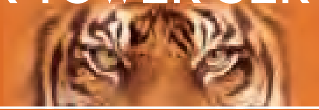

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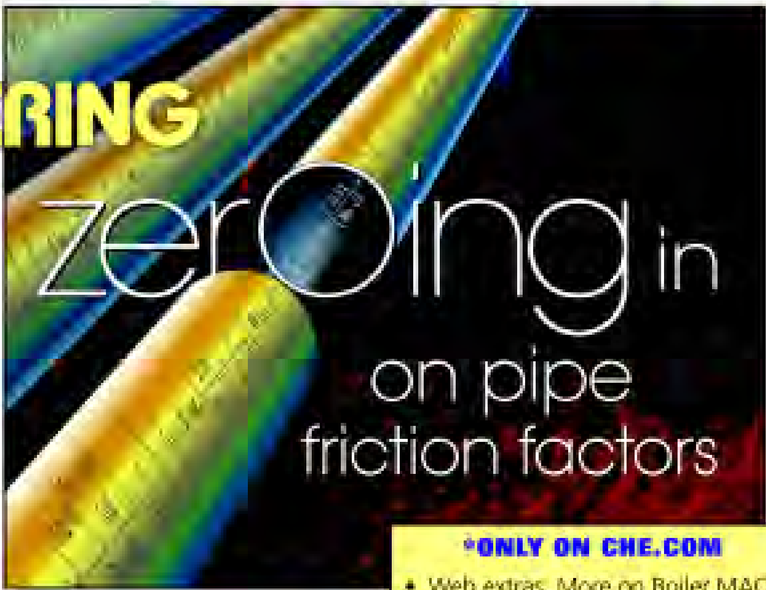

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Editor's Page

Dr. Alfred Oberholz (1952-2012)

Last month, the chemical process industries (CPI) lost an influential leader. Dr. Alfred Oberholtz died February 2, 2012 unexpectedly. He was 59.

As former chairman of Dechema e.V. (www.dechema.de), Oberholz was often found at the center of a global stage. Dechema, after all, is the organizer of Achema, the world's largest exhibition-congress for chemical engineering, environmental protection and biotechnology, which takes place once every three years, including 2012 (June 18–22; both Frankfurt am Main, Germany).

Whoever knew Alfred Oberholz immediately mentions his enthusiasm for innovation and his aspiration to think in unusual categories while also motivating others to do the same. Whether in his professional life or his many honorary engagements, he brought new things forward. He has left a large gap.

Oberholz was born in 1952. He studied chemistry at the RWTH Aachen and did his Ph.D. research with Professor Hammer and Professor Keim. He became a member of Dechema in 1977. His professional career started in 1980 at the Chemische Werke Hüls in the process engineering department. After having held several positions, he became a member of the board in 1998. From 2001, he was a member of the board of Degussa AG and from 2007 to 2008 a member of the board of Evonik Industries AG.

Throughout his life, Oberholz worked in honorary capacities. He stayed close to his university and was chairman of RWTH's university council. From 2002 to 2008, he served on the board of trustees of the Fonds der chemischen Industrie, from April 2006 as its chairman. From 2004 to 2009 he was chairman of Dechema and from 2006 to 2008 chairman of ProcessNet, the joint platform for process engineering of Dechema and VDI-GVC (the Assn. of German Engineers — Society for Chemical and Process Engineering). After his retirement, he worked for regional projects like Innovation-City Ruhr, which aims at establishing an energy efficient model region.

In all his functions, progress was close to his heart. He always kept the actual issue in focus and did not accept structural limitations. The current shape of the European platform SusChem, which he chaired from 2005 to 2008, is a testament to his initiative and ideas. When he thought that cooperation would be useful, he brought disciplines and organizations together. Early on he recognized the growing importance of Asia and especially China and established contacts between Germany and China during his many journeys. He also spoke up for industrial biotechnology and did not stop at verbal support; when he deemed it necessary, he invested time for personal meetings with responsible parties in politics and funding organizations.

Right from the start of his chairmanship at Dechema, he actively shaped its strategic orientation. He put emphasis on formulating a clearly defined core mission that could give orientation for Dechema's work. Even after his tenure, he made a significant contribution to the restructuring of Dechema as a member of the special commission of the board. Intellectual brilliance paired with sovereignty and the ability to express strategic visions clearly made him a personality who advanced ideas and enabled their implementation. His messages got through clearly, and he always was fair. In the board of Dechema, he promoted a culture of discussion and openness and encouraged everybody to actively participate.

Despite his calm and seriousness, he allowed his humor to show at appropriate occasions; whether at Achema Gala Night or the Max Buchner Evening, his lively speeches set the tone for many a societal event. His presence of thought, his sharp wit and his strategic mind set have greatly enriched Dechema's work and given many impulses. We will miss Alfred Oberholz. ■

Rebekkah Marshall, with Kathrin Rübberdt, Dechema

Letters

CE scholarship applications open

Chemical Engineering is pleased to announce that applications are now being accepted for its annual Nicholas P. Chopey scholarship program.

Bringing recognition to the value of the chemical engineering profession and striving to continually advance it have been goals for this magazine since its founding in 1902. In late 2007, *Chemical Engineering* established the scholarship in memory of the magazine's former Editor In Chief.

Applicant qualifications. Applicants to the program must be current third-year students who are enrolled in a full-time 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

If selected as a recipient, the student will receive a one-time only award that may be used for undergraduate study.

Application details. Qualified and interested students must complete the application and mail it along with a current, complete transcript of grades to the following address, postmarked no later than April 15.

Nicholas Chopey Scholarship Program
Scholarship Management Services
One Scholarship Way, P.O. Box 297
Saint Peter, MN 56082
Telephone: (507) 931-1682

Applications will be sent directly to the chemical engineering departments of the qualified schools and can also be found at www.che.com/npcscholarship/

Selection of recipients. Scholarship recipients are selected on the basis of academic record, demonstrated leadership and participation in school and community activities, honors, work experience, statement of goals and aspirations, unusual personal or family circumstances, and an outside appraisal. Financial need is not considered.

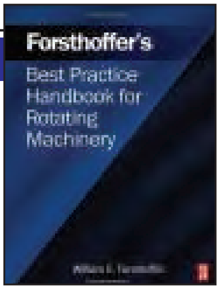
Selection of recipients is made by Scholarship Management Services, a division of Scholarship America. In no instance does any officer or employee of *Chemical Engineering Magazine* play a part in the selection. Recipients will be notified in early June.

Donations. Checks should be made out to Scholarship America, with "Nicholas Chopey Scholarship Program" in the memo area, and sent to the following address prior to June 1, 2012:

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

Postscripts, corrections

January 2012: In the Chementator article "Demo plant for high-yield biomass-to-gasoline process under construction" (p. 9), the amount of biomass to be processed at the company's planned commercial-scale facility in Pennsylvania is 44,000 tons annually (not 444,000 tons).



Forsthoffer's Best Practice Handbook for Rotating Machinery. By William Forsthoffer. Elsevier Inc., 30 Corporate Drive, 4th floor, Burlington, MA 01803. Web: elsevier.com. 2011. 672 pages. $295.00.

Reviewed by Amin Almasi,
Rotating machinery consultant, Brisbane, Australia

Rotating machines require expertise and precision that is often lacking among those responsible for operating and maintaining them. This situation underscores the need for practical guidance on pumps, compressors, turbines and other rotating machinery. Forsthoffer's book deserves a place among the best rotating-machine resources, and should be considered a valuable reference whether or not you are familiar with the earlier five-book series also written by Forsthoffer.

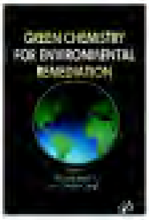
Taking an unconventional approach, the new book focuses its practical discussions around established best practices. For each topic, a best practice is presented, and then supporting materials and details are discussed. Chapter 1 reviews best practices related to the overall project, such as specification, bid evaluation, ordering, design auditing and testing. Chapter 2 focuses on pumps, covering important issues, such as NPSH, pump selection, pump control and minimum-flow bypass. Compressors are discussed in Chapter 3, which includes practices, supporting materials and data for centrifugal, reciprocating and screw compressors. Several useful and interesting topics are presented — particularly non-lubricating reciprocating compressors (which are rapidly replacing lubricated compressors in CPI plants), reciprocating compressor pulsations, gas-density changes in dynamic compressors, and integrally geared centrifugal compressors.

Chapter 4 explores best practices for gear units and couplings and discusses critical issues, such as replacing old-fashioned gear couplings with modern, flexible ones. Chapters 5 and 6 cover steam and gas turbines, respectively. Important factors in equipment selection are discussed, such as considering highly efficient aero-derivative gas turbines. Among the most useful sections are Chapters 7–9, which cover oil systems, pump mechanical seals and dry gas seals. Important issues, such as cartridge seals, pressurized dual seals, abradable-type separation seals, and seal-gas conditioning units, are discussed. Chapter 10 deals with installation, commissioning and startup of rotating machinery, and discusses practical topics, such as machinery foundation preparation, grouting, oil flushing and initial startup. The book's two final chapters are dedicated to preventive- and predictive-maintenance best practices, as well as implementation and communication best practices.

While this book skillfully covers much ground, several new technologies, such as modern electric motors, integrally geared machines, magnetic bearings, direct-driven hermetically sealed compressors and large, variable-speed electric drives (which are steadily replacing steam turbines and gas turbines as mechanical drivers) deserve more detailed coverage. Some details and practices focus on outdated technologies, such as seal oil, that may not be useful for modern projects.

Nonetheless, the author's vast expertise (more than >45 years), and the knowledge and experiences reflected in the book's best practices, supporting materials and technical details for a wide range of rotating machines should be appreciated. Those engaged in basic and detailed design, machine manufacturing, commissioning, operation and maintenance will find this book valuable. It will certainly join my library.

Food Processing Handbook. 2nd ed. Edited by James G. Brennan and Alistair S. Grandison. John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030. Web: wiley.com. 2012. 826 pages. $320.00.



Green Chemistry for Environmental Remediation. Edited by Rashmi Sangi and Vandana Singh. John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030. Web: wiley.com. 2011. 800 pages. $195.00.

Onshore and Offshore Wind Energy: An Introduction. By Paul A. Lynn. John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030. Web: wiley.com. 2011. 240 pages. $80.00.

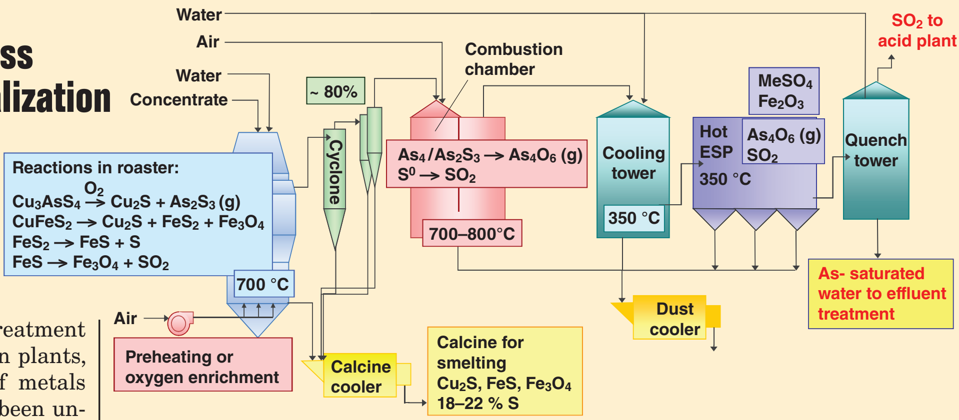
Chemistry of Modern Papermaking. By Cornel Hagiopol and James W. Johnston. CRC Press. 6000 Broken Sound Parkway, NW, Suite 300, Boca Raton, FL 33487. Web: crcpress.com. 2012. 431 pages. $179.95.

Roald Hoffman on the Philosophy, Art and Science of Chemistry. Edited by Jeffrey Kovac and Michael Weisberg. Oxford University Press Inc., 198 Madison Ave., New York, NY 10016. Web: oup.com. 2012. 390 pages. $35.00.

Principles of Tribology. By Wen Shizhu and Huang Ping. Tsingua University Press and John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030. Web: wiley.com. 2012. 536 pages. $140.00. ■

Scott Jenkins

A new roasting process slated for commercialization



Outotec Oyj (Espoo, Finland; www.outotec.com) has introduced a new partial roasting process to purify copper and gold concentrates that are contaminated with arsenic, antimony and carbon. The process is a pretreatment stage for Cu- and Au-extraction plants, and enables the extraction of metals from ores that had previously been unattractive because the impurities create a "huge problem" of handling dust laden with As and other intermediate products formed in conventional Cu or Au smelters, says Lars Hedstrom, head of Outotec's Roasting Competence Center in Skelleftea, Sweden.

In the new process (flowsheet), ore concentrate is fed to the top of a fluidized-bed roaster. Preheated air is added through a large numbers of tuyeres at the furnace bottom. The air acts as fluidization media and supplies oxygen to the roasting reactions. Heat is generated by exothermic combustion reactions whereby iron sulfide in the concentrate is oxidized to magnetite and a SO_2-rich process gas. Impurities, such as As and Sb, are vaporized at the high reaction temperature, and thus removed from the solid calcine that contains the valuable metals (normally Cu, Au and Ag). Most of the calcine is pneumatically transported out from the roaster and separated from process gas in cyclones; the more-coarse fraction of calcine leaves the roaster through the bed outlet. The calcine is cooled to stop further reactions between calcine and air. This cooled calcine is now a raw material to conventional copper smelters. It contains enough sulfur to be mixed with conventional copper concentrates to make a suitable feed for oxygen based processes.

Meanwhile, the process gas contains combustible sulfur compounds, such as arsenic sulfide and elemental sulfur; these compounds are oxidized in the post-combustion chamber using preheated air. The process gas, now only containing oxide compounds, is cooled in a cooling tower and then cleaned of its dust content in a hot electrostatic precipitator (ESP). Arsenic oxide passes through the ESP and is collected in a wash solution when the gas is quenched in a washing tower. The SO_2-rich process gas is further cleaned and converted into sulfuric acid. Arsenic is converted into stable compounds by separate conversion processes, which are also supplied by Outotec.

The process was first demonstrated about 30 years ago in a 45-ton/h plant, which is still operated by Boliden in Sweden. Outotec is now operating a 25-kg/h pilot plant in Frankfurt, Germany. The company is also currently building the world's largest As-removing roasting furnace at Codelco Mina Minstra Hales mine near Calama, northern Chile. The new plant will treat up to 550,000 metric tons (m.t.) of Cu concentrate per year and it will produce approximately 250,000 m.t./yr of H_2SO_4. More than 90% of the As contained in the concentrate will be removed, says the company.

Adding gallium to biomass pyrolysis catalyst increases BTX yield

A new catalyst design, in which gallium atoms are integrated into the zeolite catalyst structure, can increase yields of aromatic compounds from biomass by 40% in a catalytic fast-pyrolysis process. The higher yields of benzene, toluene and xylenes (BTX), as well as ethylene and propylene, achieved with the gallium-containing zeolite, make the biomass process economically competitive with crude-oil-based production of those building-block chemicals. George Huber, chemical engineering professor at the University of Massachusetts at Amherst (www.umass.edu) and leader of the research group that developed the new catalyst, says the gallium modifies the properties of the zeolite's surface-active sites in a way that favors key reactions in the biomass pyrolysis — de-carbonylation and oligimerization of the biomass. The fast- pyrolysis process involves feeding wood- or agricultural-waste into a fluidized-bed reactor, where the biomass decomposes with heat. The resulting vapor encounters the new gallium-zeolite catalyst, and is selectively converted into aromatics and olefins. The team's fast pyrolysis technology has been licensed to Anellotech Inc. (New York, N.Y.; www.anellotech.com), a company Huber co-founded (*Chem. Eng.*, August 2009, p. 13).

Solar thermal power

The first solar-thermal power plant in Southeast Asia fed its full output of 5 MW into Thailand's public grid for the first time late January. The facility — designed and built by Solarite GmbH (Duckwitz, Germany; www.solarlite.de) — is also the first commercial solar-thermal plant to produce steam directly from water, thereby eliminating the need for heat-transfer fluids and heat exchangers. Water flows through absorber tubes at the focal line of parabolic troughs, which collect the radiation and generate steam

(*Continues on p. 10*)

Note: For more information, circle the 3-digit number on p. 70, or use the website designation.

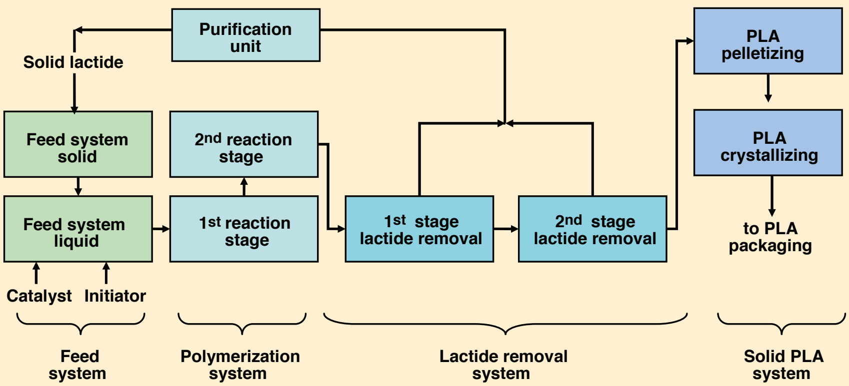
A new PLA process makes its commercial debut

Earlier this year, the first polylactic acid (PLA) plant based on a new polymerization process was put into service by Synbra Technology in Etten Leur, the Netherlands. The plant — capable of producing up to 5,000 ton/yr of PLA — was built by Sulzer Chemtech Ltd. (Winterthur, Switzerland; www.sulzerchemtech.com), and uses a PLA process jointly developed by Sulzer Chemtech and Purac (Gorinchem, the Netherlands; www.purac.com), a company of the Dutch CSM group.

PLA is made (flowsheet) by the ring-opening polymerization of lactide — a cyclic dilactate ester, which is produced by the esterification of two lactic-acid molecules, followed by a catalytic cyclization reaction. Unlike conventional routes, the melt-based process does not require solvents, and is able to produce all different grades of PLA, with a wide range of molecular weights, in a single line, says Torsten Wintergerste, Director of PolyTechnology at Sulzer Chemtech. The continuous process also takes advantage of Sulzer Chemtech's proprietary static-mixing technology, which reduces maintenance and the plant's footprint, as well as simplifying scaleup and plant operation, he says.

The new process is also able to convert stereochemically pure L- and D-lactide — available from Purac — into a stereochemically pure PLA. This enables the production of high-temperature-resistant (up to 180°C) PLA and stereo-complex PLA grades, says Wintergerste.

To further support customer application development for PLA grades and demonstrate its polymerization technology, Sulzer is building its own PLA production plant. The 1,000-ton/yr plant will be operational early this year at a company's site in Switzerland.



Biobutanol to be produced at retrofitted ethanol plant

The first commercial-scale biobutanol plant using the Gevo Integrated Fermentation Technology (GIFT) process is set to come online in mid-2012 at the former site of an ethanol facility in Minnesota. In late January, Gevo (Englewood, Colo.; www.gevo.com) was awarded a U.S. patent for the GIFT separation technology, a key component of the process that allows the separation of C3–C6 alcohols from the fermentation broth. "The challenge for biobutanol is that, above certain concentrations, the compound is toxic to microorganisms," explains Chris Ryan, Gevo's president and chief operating officer. "We've found a way to continuously remove the isobutanol as it is produced by the yeast, so the concentrations in the fermentation broth remain low." The Gevo process takes advantage of the lower-boiling azeotrope formed by butanol and water. The azeotrope is continually evaporated from the fermentation broth and condensed. The isobutanol then phase-separates from water.

At the front end of the process, Gevo has genetically modified a commercial yeast strain previously used for ethanol production so that it now produces high levels of isobutanol from carbohydrates without large amounts of byproducts.

Bio-based butanol can be substituted for petroleum-derived butanol in traditional butanol applications as a specialty chemical, or in applications such as gasoline blendstock, for making iso-octane or for producing butene via well-known dehydration reactions. Butenes are key feedstocks for the manufacture of some plastics and fibers.

(*Continued from p. 9*)

(at 330°C and 30 bars) for running the turbine. Solarite uses a combination of recirculation and injection technology to maintain a stable temperature and pressure.

Compared to the 395°C limit for thermal oils, the direct-steam-generation technology allows, in principle, higher operating temperatures of 500°C, which lead to a corresponding increase in plant efficiency, says the company, which notes that the plants are 25% more efficient than photovoltaic power plants. A second power plant is under development — TSE2 — that will operate at 400°C and 40 bars pressure.

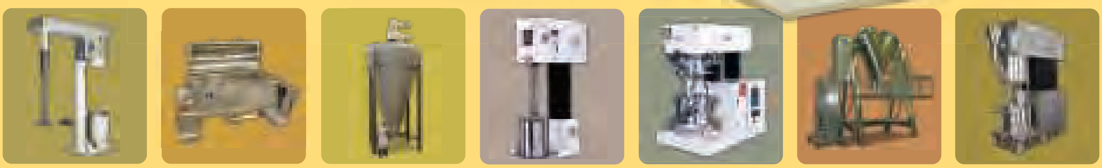
The technology was developed and pilot-tested with cooperation from the German Aerospace Center (DLR; Cologne, Germany; www.dlr.de). In collaboration with Thai Solar Energy Ltd. (Bangkok; www.thaisolarenergy.com) — the investor and operator for TS1 and TS2. Solarlite is planning 15 more power plants in the region with a total capacity of 135 MW.

A new separator for LIBs

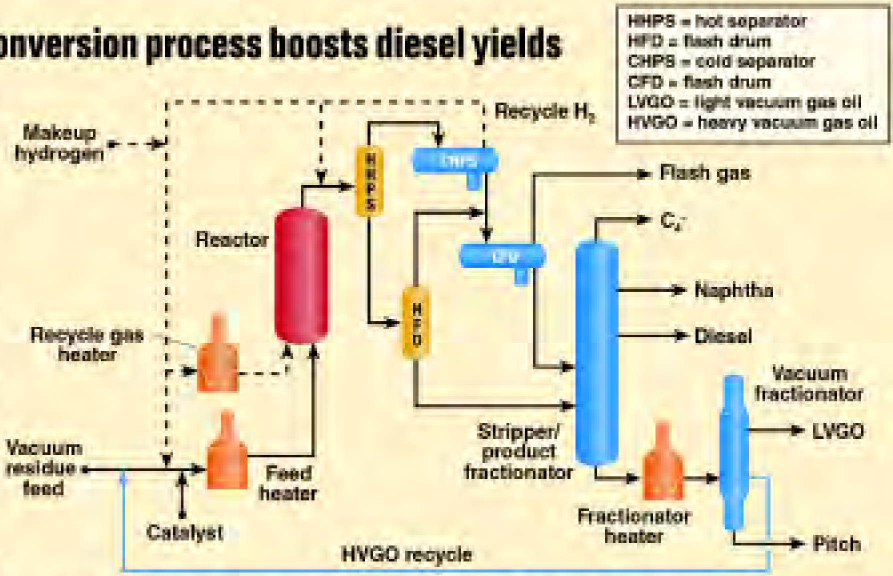
Last month, Teijin Ltd. (Tokyo, Japan; www.teijin.co.jp) launched a new separator for lithium-ion secondary batteries (LIBs) that uses a fluorine-based coating, which achieves superior heat resistance and adhesion thereby improving output and safety in laminated-type LIBs used in tablets and smart phones. Marketed under the Lielsort brand, the new separator is coated with Teijinconex meta-aramid, and is said to achieve "unprecedented" capacity and energy density, as well as enhanced safety and lifespan for liquid-electrolyte cylindrical LIBs used in PCs and vehicles. The company developed a process for simultaneously coating both sides of the separator, and a high-speed coating technology that is five times faster than conventional coating methods.

To support full-scale commercialization, Teijin has established a separator manufacturing company — Teijin CNF Korea Co. (Asan, Korea) — a joint venture (JV) with film-processor CNF; this JV will begin production in

(*Continues on p. 12*)



Improved heavy-crude conversion process boosts diesel yields



A proprietary nanoscale catalyst and an updated engineering design have allowed higher conversion rates for transforming the heaviest fractions of crude oil, known as vacuum residue, into high-value transportation fuels, such as diesel.

Developed by UOP LLC (Des Plaines, Ill.; www.uop.com) and called Uniflex, the technology combines elements of the CANMET hydrocracking process used by Petro-Canada from 1985–2003) with elements from UOP's hydroprocessing technologies. Traditional approaches for refining the bottom-of-the-barrel, such as delayed coking, result in 65–75% conversion to transportation-fuel products, but Uniflex can achieve 90% conversion — mostly to diesel and naphtha. Uniflex diesel yields are usually double those from delayed coking.

"The demand for low-grade fuel oil is decreasing, while the demand for diesel is growing," says Bob Haizmann, director of UOP's heavy oils business. "So there's a real market opportunity for converting the heavy portion of crude oil."

UOP's updated process includes a fine-particle catalyst that is blended with the feed stream, so that the nanoparticles flow along with the process stream and prevent coke formation by managing interactions and conversion of the asphaltene portion of the vacuum residue. The process is based on an upflow, liquid-full reactor into which a H_2-rich gas is bubbled (diagram). The reactor design promotes vigorous backmixing, which helps maintain near-isothermal conditions, allowing higher operating temperatures, and thus higher conversion rates. Also, the modernized engineering design package minimizes utility costs, Haizmann says.

In January, UOP announced that the Uniflex process was selected to help maximize diesel and lubricant production at a plant operated by National Refinery Ltd. (Karachi, Pakistan; www.nrlpak.com). The facility, slated to begin production in 2016, will generate 40,000 bbl/d of diesel fuel and 4,500 bbl/d of lubricant oils.

Using chemistry to protect structural steel during a fire

A technique for protecting structural steel from fire using the endothermic decomposition of magnesium hydroxide has been developed by a team from the Dept. of Chemical Engineering and Materials Engineering, the University of Auckland (New Zealand; www.auckland.ac.nz). Led by professor Mohammad Farid, the team designed a system consisting of an outer layer of gypsum board and an inner mass of $Mg(OH)_2$. The presence of water molecules in the gypsum (mainly $CaSO_4{\cdot}2H_2O$) is crucial in establishing its fire-resistance properties. Heat causes the waters of hydration to be released from the gypsum. The dehydration reactions, which occur between 125 and 225°C, are strongly endothermic.

The team's experimental work shows that the addition of the $Mg(OH)_2$ increased the thermal mass of the system and removed heat through its endothermic decomposition. At 350°C $Mg(OH)_2$ decomposes to MgO and H_2O, absorbing 70 kJ/kg. When only MgO is used for protection, the time for the steel to reach 550°C is increased from 50 to 88 min. When MgO is replaced by $Mg(OH)_2$, the time needed for the steel to reach 550°C is increased further to 112 min.

The thermal decomposition of $Mg(OH)_2$ occurs in two stages. The first stage involves the release of water, which occurs between 20°C and 350°C. The second stage involves breaking the $Mg(OH)_2$ bonds and the formation of MgO and water, which begins at a temperature of 350°C and continues to a temperature of 500°C.

The team says the ideal application of the endothermic reaction material would be to sandwich it inside two layers of gypsum board, ensuring the steel would not be able to reach temperatures above 250°C until the reaction had reached its completion.

(Continued from p. 10)

June. Teijin has also established a wholly owned subsidiary, Teijin Electronics Korea Co. (Seoul), to market the separators.

Lithium-ion storage

Researchers from Gießen University, the University of Calif. at Los Angeles, the German accelerator Center (Deutsches Elektronen Synchrotron DESY) and HRL Laboratories have identified a promising new material for use in Li-ion batteries — porous thin films of hematite (α-Fe_2O_3). Using electrochemical methods, the researchers found that mesoporous (20-nm-dia. pores) films store over thirteen times more Li^+ ions than hematite microcrystals, and in the voltage range used in the study, the thin films even surpass the specific capacities of other known Li-battery materials. ❑

Composites that can enhance forward osmosis

Researchers from the Dept. of Chemical Engineering, Monash University (Clayton, Victoria, Australia; www.monash.edu), have reported on a new composite polymer hydrogel with light-absorbing particles incorporated within it, that can be used as draw agents in the forward osmosis (FO) process of desalination.

The researchers, led by professor Huanting Wang, aimed to develop new "draw agents" capable of meeting the following requirements: low-energy consumption for regeneration, complete separation from the fresh water product, low toxicity and chemical inertness with polymeric membranes.

They have previously shown that hydrogel particles are able to draw pure water through FO membranes. The water can then be removed by pressure or heating, or both. The incorporation of light-absorbing particles leads to natural, enhanced heating and dewatering of the composites, as compared with pure hydrogels under irradiation with light. Another advantage of composite polymer hydrogels is that they exhibit higher swelling ratios, thus producing higher water fluxes in the FO process. With increasing loading of carbon particles, the water recovery rates from the swollen composite hydrogels are greatly enhanced.

The hydrogels are synthesized by free-radical polymerization of different monomers (such as sodium acrylate, N-isopropylacrylamide) and the crosslinker N,N'-methylene-bisacrylamide, with light-absorbing carbon particles.

Very rapid cooling enables a new way to produce magnesium

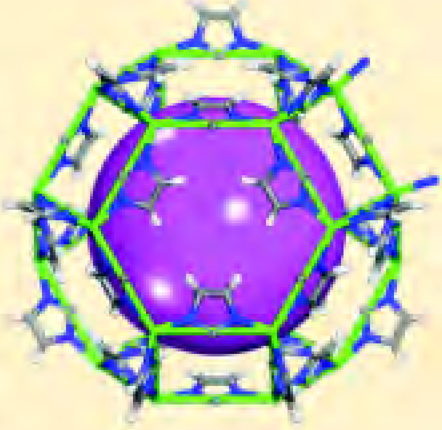
A carbothermal process for obtaining magnesium — developed by CSIRO (www.csiro.au) Light Metals Flagship (South Clayton, Victoria, Australia) — overcomes previous limitations to commercial viability. For several years, magnesium has been produced mainly by electrolytic routes, from magnesium chloride sources such as seawater and natural brines. More recently, world production has been mainly in China, using the Pidgeon process, where ferrosilicon reduces magnesia from calcined dolomite under vacuum. One of the main problems with those methods is the reversion of Mg and CO_2 to magnesium oxide and carbon as the vapors cool.

The CSIRO process, called MagSonic, uses shock-quenching to achieve extremely rapid cooling — up to 10^6 °C/s — of the gaseous reaction products and prevent the back reaction. According to CSIRO, carbothermic reduction is a much cheaper reduction than ferrosilicon, and there is significant potential for reduction in equipment size, capital costs, and productivity over electrolytic routes.

In the MagSonic process, magnesia and carbon (graphite) react above 1,700°C to produce Mg vapor and CO gas. The equilibrium total pressure of the products is 1 atm at 1,764°C. In CSIRO's experimental work, a charge of up to 2,500 g of briquettes of MgO and graphite were heated under inert gas at atmospheric pressure. The gas phase was shock-

(*Continues on p. 14*)

This MOF selectively captures radioactive iodine



A challenge in recovering fissile material from spent nuclear fuel is separating radioactive components that cannot be reused as fuel. Researchers at Sandia National Laboratory (Albuquerque, N.M.; www.sandia.gov) have fabricated metal-organic frameworks (MOFs) capable of selectively capturing gaseous iodine from a stream of spent nuclear fuel.

MOFs are crystalline materials in which metal atoms are bound to organic molecules that coordinate through self-assembly to form rigid and often porous three-dimensional structures. After extensive studies of iodine-capturing zeolites, the Sandia team used commercially available compounds to develop an MOF that is capable of capturing iodine within the pore structure of the material.

The team also developed a process to pelletize the MOF material into a more stable and durable material, and one to incorporate the MOF with its pore-trapped iodine into glass waste for long-term storage.

New Way to Produce Magnesium

(Continued from p. 13)

quenched by supersonic flow through a de Laval nozzle at four times the speed of sound, to condense Mg metal, which was separated from the CO by cyclone.

The CSIRO team tried to understand a form of reaction that produces a steady overall reaction rate, and therefore constant gas composition in the supersonic quenching nozzle — a "pseudo-steady state" control. The reactor temperature is controlled; it is slowly increased as the mass of reactants decreases to maintain pressure in the reactor. A pseudo-steady-state operation was achieved for more than an hour, and the temperature profile matched a cubic function, as expected from kinetic studies.

The CSIRO team used a scaled-up rig, with an increased reactor capacity, to optimize the size of the magnesium particles produced and to improve the collection system. The lead researcher, Leon Prentice, plans to operate a pilot plant to test the process' commercial viability.

Nanosized zeolite catalyst shows promise for improving naphtha cracking

A naphtha-cracking process with improved yield, reduced coking and longer catalyst life is being developed in a five-year Japanese project led by professor Takashi Tatsumi at the Tokyo Institute of Technology (TiTech; www.titech.ac.jp), with participation from the National Institute of Advanced Industrial Science and Technology (AIST), Hokkaido University, Yokohama National University, three petrochemical companies and an engineering company. The NEDO (New Energy and Industrial Technology Development Org.; Kawasaki) project, "Basic Technology Development of Revolutionary Naphtha Cracking Process Using Catalyst," stated earlier this year and has already achieved promising results.

Using a nano-sized zeolite catalyst and a small reactor system, the researchers have shown that they can increase the propylene-to-ethylene ratio to 1.0, compared to a maximum of 0.7 achieved in conventional systems. Compared to thermal cracking, a 10% increase in "valuable" products, such as ethylene, propylene, butanes and BTX (benzene, toluene and xylenes) was achieved.

Two basic catalysts were selected from 27 candidate zeolites, and fabricated as nano-sized particles with 100–200-nm dia. — one-tenth the size of commercial catalysts. The combination of the increased surface area of the nano catalyst, the addition of steam and the operation of the process at a lower temperature (650°C compared to 800°C for thermal cracking) drastically reduced the formation of carbon deposits on the catalyst, says Tatsumi. As a result, the catalyst activity remained high for a longer period of time compared to conventional catalysts, which are prone to coking.

The researchers have now moved to a semi-bench-scale reactor located at the Institute for Chemicals Resources, TiTech Suzukadia Campus, and capable of processing 1 kg/d of naphtha. The project objectives are to boost the ethylene and propylene yield to more than 50%; achieve a continuous operation of 48 h, with catalyst regeneration every 8 h, and a 90% catalyst activity after five regeneration cycles.

A fine filter

Last month, W. L. Gore & Associates (Gore; Elkton, Md.; www.gore.com) introduced what is claimed to be the world's first 20-nm-rated polytetrafluoroethylene (PTFE) filter that is available in a high-density polyethylene (HDPE) cartridge. Compared to conventional filtration media, this new PTFE membrane technology provides a significantly increased open-porous area available for fluid flow, and the structural characteristics of the membrane provide a high level of retention, says Gore. The new PTFE/HDPE filter cartridges are optimized for the bulk processing of high-purity chemicals used in the fabrication of semiconductors and flat panel displays, and are now available in three retention ratings: 100, 30 and 20 nm. ■

Circle 41 on p. 70 or go to adlinks.che.com/40265-41

Newsfront

ROAD TO BOILER MACT TAKES SHARP TURNS

District court overturns EPA's stay, EPA issues a 'no action assurance letter' and industry calls for legislative action so EPA can 'get it right'

WHAT WILL EPA NOT ENFORCE, AND FOR HOW LONG?

In EPA's No Action Assurance letter, it states that EPA will exercise its discretion not to pursue enforcement for the following violations, but emphasizes that the No Action Assurance applies only to the timeliness of these requirements, not to the underlying requirements themselves.

Major Source Boiler MACT:

- Failure to submit a complete Initial Notification by the dates required under the Major Source Boiler MACT (see 40 CFR 63.7545(b) & (c))

New Sources Under the CISWI Rule:

- Failure to submit in a timely manner a complete notification prior to construction containing all elements identified in 40 CFR 60.2190
- Failure to submit in a timely manner a notification of construction as required by 40 CFR 60.2230 that complies with 40 CFR 60.7(a)(1)
- Failure to submit in a timely manner a notification of startup as required by 40 CFR 60.2230 that complies with 40 CFR 60.7(a)(3)

The exercise of discretion is subject to the following conditions:

- The No Action Assurance is to remain in effect for the above-listed Major Source Boiler MACT provisions until either: 1) 11:59 p.m. EDT, December 31, 2012, or 2) the effective date of a final rule addressing the proposed reconsideration of the Major Source Boiler MACT, whichever occurs earlier
- The No Action Assurance is to remain in effect for the above listed CISWI provisions until either: 1) 11:59 p.m. EDT, April 30, 2013, or 2) the effective date of a final rule addressing the proposed reconsideration of the CISWI rule, whichever occurs earlier

The EPA has proposed new notification deadlines in its proposed reconsideration of each rule [2], and if the agency takes final action to adopt those proposed deadlines, they will control. ■

Already, in the first two months of this year, the unpredictable and winding road of the so-called Boiler MACT, has taken yet another set of hair-pinned curves. Now industry groups are pushing even harder for an act of Congress that would put on the brakes and allow more time for the regulations to be reshaped. At stake, says Robert Bessette, president of the Council of Industrial Boiler Owners (CIBO; www.cibo.org; Warrenton, Va.), are over 220,000 jobs and over $14 billion in capital costs that would be required for over 1,700 major-source units.

The regulation in question involves new emissions standards for hazardous air pollutants (HAPs) emitted by industrial boilers, process heaters and commercial and industrial solid-waste incinerators (CISWI), based on the performance of the maximum-achievable control technology (MACT). In March 2011, the U.S. Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov) issued the final rule, but then in May pulled back with an administrative "stay" of the regulation pending reconsideration. The stay was called for by CIBO, the American Chemistry Council (ACC; Washington, D.C.; www.americanchemistry.com) and a host of other influential industry groups because of concerns that parts of the rule were not achievable and did not give industry enough time to identify, budget for and implement the necessary changes to their facilities.

While the stay provided a brief, fleeting sigh of relief to industry and gave EPA over six months to reconsider the rule, it kicked up the dust in terms of uncertainty. In fact, the confusion came to a head in January 2012, when the U.S. District Court for the District of Columbia issued a decision that overturned the U.S. EPA's stay of the March 2011 rules.

The court decision left many in the regulated community scrambling. As Leslie Hulse, assistant general counsel for ACC explains, "With the loss of the stay, the rule became effective on May 20, 2011. This means that existing sources are [technically] out of compliance with at least one administrative requirement: submittal of initial notifications." Acknowledging the ambiguity of the situation, EPA issued a letter on February 7 to ACC and seven other industry groups [*1*], informing them that the agency will not enforce the submittal deadlines for certain notification requirements in the March 2011 rule (see box, above).

EPA explained that letter in a statement to *CE* on February 10, 2012:

The letter applies to new and existing sources under the boiler rule and to new sources under the incinerator rule. This action clarifies how EPA expects [emission] sources to act in light of a recent court decision, and will ensure that no unnecessary steps will need to be taken to implement certain requirements that the agency will replace later this year.

The court's decision does not impact the agency's reconsideration proposals issued in December 2011 [see box, p. 19]. *EPA is currently receiving public comments on the proposed reconsidered rules, and EPA will finalize them later this year, after reviewing and responding to stakeholder comments.*

The final rules will address the compliance dates for existing sources, as well as the initial notification requirements addressed by the No Action Assurance letter. It is EPA's current intention to work toward final rules that give entities the full compliance period as allowed by the Clean Air Act with a possibility of an additional year to install control technology, as allowed on a case-by-case basis under the Clean Air Act. The CISWI rule does not contain notification requirements for existing sources that cause a need for enforcement discretion.

Costs of proposed rule

Whenever the rule is enforced, the Boiler MACT will require emissions controls for particulate matter (PM), hydrogen chloride, mercury and carbon monoxide. According to a January 2012 update, which applies to the EPA's December 2012 proposed modifications to the rule, CIBO estimates that the total capital cost to comply will be $14.3 billion and will threaten over 220,000 jobs [*3, 4*], which is more than double EPA's $5.4 billion estimate [*5*].

CIBO's estimate was developed with URS Corp. (San Francisco, Calif.; www.urscorp.com) and covers the technologies that EPA has identified as necessary to comply with the Boiler MACT: a fabric filter for PM control, carbon injection for control of Hg, a scrubber for control of HCl and combustion improvements or an oxidation catalyst for control of CO. Estimated costs (Table 1) are based in large part on information in EPA's December 2011 survey and emissions databases, CIBO says.

In CIBO's estimates, information from various sources was used to determine a base capital cost for a 250 million Btu/h boiler for each PM, CO and HCl control technology option and then scaled based on the size of each boiler in the inventory. For example, the report says, the capital cost of a wet scrubber on a 100 million Btu/h boiler is calculated as the base cost times $(100/250)^{0.6}$. A fixed cost of $1 million was assumed for installation of a carbon adsorption system for Hg control, since these systems do not vary much in cost by boiler size. Base cost assumptions are presented in Table 2 (ESP is electrostatic precipitator).

CIBO maintains that in some cases the emission limits will be very difficult to achieve over all operating conditions using the technologies EPA has identified, but the CIBO cost analysis does not factor in additional costs that would be associated with alternate technologies. With that in mind, the CIBO analysis explains that it differs from the EPA analysis as follows:

• EPA has used the outdated Control

EPA'S PROPOSED CHANGES TO FINAL RULE

In December 2011 [*2*], after conducting additional analyses, EPA proposed the following changes to the original rule that was promulgated in March 2011:

- Create new subcategories for light and heavy industrial liquids to reflect design differences in the boilers that burn these fuels. This change would improve the standards' achievability
- Set new emissions limits for PM that are different for each solid fuel subcategory (such as, biomass and coal) to better reflect real-world operating conditions
- Set new emissions limits for carbon monoxide based on newly submitted data that shows CO emissions from boilers vary greatly. EPA is proposing to set new limits to more adequately capture that variability
- Allow alternative total selective-metals emission limits to regulate metallic air toxics instead of using a PM as a surrogate, allowing more flexibility and decreasing compliance costs for units that emit low levels of HAP metals
- Replace numeric dioxin emissions limits with work practice standards to reflect a more robust analysis that shows dioxin emissions are below levels that can be accurately measured
- Increase flexibility in compliance monitoring to remove continuous emissions monitoring requirements for particle pollution for biomass units and to propose carbon monoxide limits that are based on either stack testing or continuous monitoring
- Revise emissions limits for units located outside the continental U.S. to reflect new data and to better reflect the unique operating conditions associated with operating these units
- Continue to allow units burning clean gases to qualify for work practice standards instead of numeric emissions limits, maintaining flexibility and achievability. EPA is proposing to remove the hydrogen sulfide fuel specification from the rule. An H_2S fuel specification does not provide a direct indication of potential HAP from combustion of gaseous fuel. Units would need to prove gas is clean by considering mercury only ❑

Cost Manual, while CIBO has based its cost estimates on more recent information, including actual vendor cost estimates, actual project costs, best available control technology (BACT) and best available retrofit technology (BART) analyses, industry control cost studies, and so on

- CIBO used a higher CO-abatement catalyst cost than EPA's. The CIBO cost is based on a recent quote from BASF, while EPA's is based on the 1998 Control Cost Manual section on catalytic oxidizers for VOC (volatile organic compound) control
- EPA has estimated that a tune-up or burner replacement will be adequate for many units to achieve the CO limits. CIBO does not agree with this assumption because some of the CO limits are fairly low and must be met over all operating conditions except startup and shutdown. So, CIBO estimated higher costs to implement new combustion controls, burner replacements, fuel-feed system improvements, or CO-abatement catalyst
- CIBO's CO-control capital costs are higher than EPA's, mostly because EPA assumed that tune-ups and replacement burners will be adequate for the vast majority of boilers to comply, and CIBO disagrees with that assumption
- EPA has estimated that activated-carbon injection will be required on only

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35 existing units because installation of a fabric filter is expected to achieve the mercury emission limits, except in cases where a unit already has a fabric filter and does not meet the limits. CIBO does not agree that fabric filters will be sufficient to reduce mercury emissions to some of the ultra-low levels in this rule. "There is a flaw in the logic that fabric filters are expected to achieve mercury emission limits when there are many boilers in the database that are equipped with fabric filters and have measured mercury emissions higher than the applicable limit. EPA's estimated industry-wide capital cost for activated carbon injection [5] is extremely low, at only $115,000 per unit"

- EPA has estimated costs to install packed-bed scrubbers for HCl control. CIBO notes, however, that "industrial boilers do not use packed-bed scrubbers for acid-gas control, as the limitations of these devices make them impractical for use on applications with high flowrates, high PM loading, and high inlet-pollutant concentration. EPA's own fact sheet on these devices lists the limitations of these devices and indicates that they are only used in applications up to 75,000 scfm, which limits their use to small units only." Facilities will instead install wet scrubbers, dry scrubbers, or semi-dry scrubbers to control acid-gas emissions from industrial boilers, CIBO says

Calling for regulatory relief

Given the delicate state of the U.S. economy, the significant costs at stake and the uncertainty that still looms, industry groups like CIBO and ACC have stepped up lobbying efforts. "Without legislation specifically interpreting the act or telling EPA and the courts how to do it, the uncertainty is increased regarding ENGO [environmental, non-governmental organizations] and the DC Circuits ruling on certain litigation to follow," says CIBO's Bessette. "Any of the good things EPA has done, like work practices, could be lost, which could result in gas-fired boilers needing controls — and that could be another $50 billion in capital costs for industry."

At this point, their hopes are pinned on the EPA Regulatory Relief Act. The House of Representatives introduced its version of the bill (H.R. 2250) in June 2011 and passed it in October 2011. The Senate's version of the legislation, S. 1392, currently has 41 bipartisan cosponsors. "We are and will be trying to make sure H.R. 2250 language or something like it is included

TABLE 1. ESTIMATED CAPITAL COST TO UPGRADE ALL AFFECTED SOURCES (BY EMISSION TYPE)

PM	$5 billion
HCl	$6 billion
Hg	$468 million
CO	$2.8 billion
Total	$14.3 billion

TABLE 2. BASE COST ASSUMPTIONS FOR A 250 MILLION Btu/h BOILER

Fabric filter (FF)	$7 million
Scrubber	$8 million
Scrubber/FF/ESP upgrade	$4 million
Carbon injection for Hg	$1 million
Combustion, fuel feed improvements or catalyst for CO	$3 million

RESOURCES AVAILABLE ONLINE

The following resources, which are referenced by number in brackets within this story, are available for download in the online version of this story*:

1. EPA's No Action Assurance Letter
2. EPA's December 2011 Proposed Reconsideration of Final Rule
3. CIBO's "How Costs Were Determined for CIBO Boiler MACT Impacts Study"
4. CIBO's Economic Impact Analysis: Estimate of State Level Impacts of Potential Jobs at Risk
5. EPA's updated cost-impact analysis (12/2012)
6. Multi-association letter to Congress, urging support for EPA Regulatory Relief Act

* The story and further developments can be found at www.che.com, under Web Extras. To access these files, look under the Online Extras Tab at the top of the story.

in whatever vehicle is available to move it," says CIBO's Bessette.

Legislative vehicles come in unexpected forms, and at *CE* press time, consideration to include the act as part of the conference agreement on payroll tax-cut extension legislation (H.R. 3630) appeared to have been discarded. (For more on the status as it develops, check the online version of this story at www.che.com.)*

The reasons for passing the Relief Act, as detailed in a multi-association letter to members of Congress [*6*], are that serious challenges still remain:

Jobs are in jeopardy. In the re-proposed rules, some standards became more stringent, and some limits may not be achievable, especially in the current three-year compliance timeframe.

Serious legal uncertainty. The court decision overturning EPA's stay of the March 2011 rules is yet another example of the continuing morass of uncertainty surrounding the rules — a problem legislation would solve.

Important biomass materials are still not listed as fuels. This means that the boilers burning these materials could be regulated under the onerous and stigmatizing incinerator standards, or the material would be land filled.

Inadequate capital planning time. The rules do not provide enough time for capital planning and compliance, given their complexity and competition for a limited pool of qualified domestic vendors and installers. Businesses need five years to fully comply with the rules, not the two or three years in the current rules.

Inadequate time to finalize rules. EPA's current rulemaking schedule is so accelerated that it is unlikely all the comments and data that will be received during the current comment period can be fully analyzed and utilized. Moving too fast increases the likelihood that the final rules will be overturned again.

EPA declined to comment on the act that is being considered in Congress. ■

Rebekkah Marshall

A LOOK AT SCREENERS

FIGURE 1. Sweco Fusion screens eliminate the use of adhesive, epoxy or silicone in screen manufacturing. Instead, the mesh is fused directly to the polymer tension ring

Screening equipment manufacturers are improving capacities and making changes that reduce maintenance time and costs

If you were to ask chemical processors what they're looking for from their screening equipment, it's likely that the answers would be as varied as the chemicals they produce because screening requirements are entirely dependent upon the material being screened. However, equipment providers say that no matter the application, minimal downtime and maintenance costs and the ability to get more efficiency and capacity from screeners is at the top of every processor's list.

"Global competition is the primary driver for these requirements," says A. J. DeCenso, business development manager with Sweco (Florence, Ky.). "In high labor markets like the U.S. and Europe, there is a huge emphasis on reducing the man-hours necessary for maintenance. This has led process equipment manufacturers to design machines with improved reliability and ease of maintenance."

Rob O'Connell, executive vice president with Russell-Finex (Pineville, N.C.) agrees. "We are now designing equipment with very low maintenance needs," he says. "The last thing our customers want is to look after their screening equipment more than necessary. The longer it can run without any attention, the higher the productivity for the line or plant," he says. "We are working to make that possible."

Simplified maintenance

One of the most commonly replaced wear parts on a screening machine is the screen itself. Some of the latest developments are aimed at reducing the labor costs associated with replacing the screen. And since safety and ergonomics are also important to processors, many vendors are working on features that enable a single operator to easily and comfortably change screens, even larger ones, without heavy lifting.

To that end, Sweco round separators have a "Quick-Change" accessory that eliminates the need to remove the frame from the separator. And the company's rectangular units all feature access doors and slide-in screen panels.

Sweco Fusion screens (Figure 1) eliminate the use of adhesive, epoxy or silicone in screen manufacturing, instead fusing the mesh directly to the polymer tension ring. This practice provides precise tensioning, lower tolerance and smaller deviations of the screen. Construction integrates the screen gasket directly into the tension ring, which eliminates the handling and stocking of separate gaskets and provides a precision fit into the separator, reducing downtime and simplifying maintenance. The design also reduces cracks and crevices, resulting in an easier-to-clean screen with less potential for cross contamination.

Rotex Global (Cincinnati, Ohio) has also been working on making the machines easier to maintain. "The Apex product line (Figure 2) was designed with ergonomics in mind. Additionally, reducing downtime by allowing employees to inspect and change screens easily was a key factor in the design," says Rob Scheper, director of global business development for Rotex.

The Apex has been designed with side-panel doors that simplify access to the screens and ball trays, so it is no longer necessary to remove the top cover to access these areas. This reduces screen-changing time by 95%, and reduces downtime, according to Scheper. In addition, the screen panels weigh only 5 lb, so one person can perform maintenance and inspections.

The Apex uses a unique gyratory-reciprocating motion for efficient distribution, stratification and separation, which helps reduce wear and tear on the machine because it doesn't vibrate in the traditional sense. Instead, it begins with a horizontal circular motion at the feed end that immediately spreads the material across the full width of the screen. The circular motion gradually changes along the length of the machine to an elliptical path, and finally to an approximate straight-line motion at the discharge end. This motion allows the machine to process material at a higher capacity and improves screening performance for near-size material. Because there is no vertical component to the motion, material is kept in constant contact with the screen surface, allowing for more efficiency and capacity.

Midwestern Industries (Macon, Ga.) has found another way to reduce machine maintenance via its ME Series vibratory, round separators. The drive design in this machine features a variable-speed pulley system integrated with the motor mounted on an adjustable slide base to achieve precision screening, while providing other benefits. The adjustable base allows for control of frequency, with an opera-

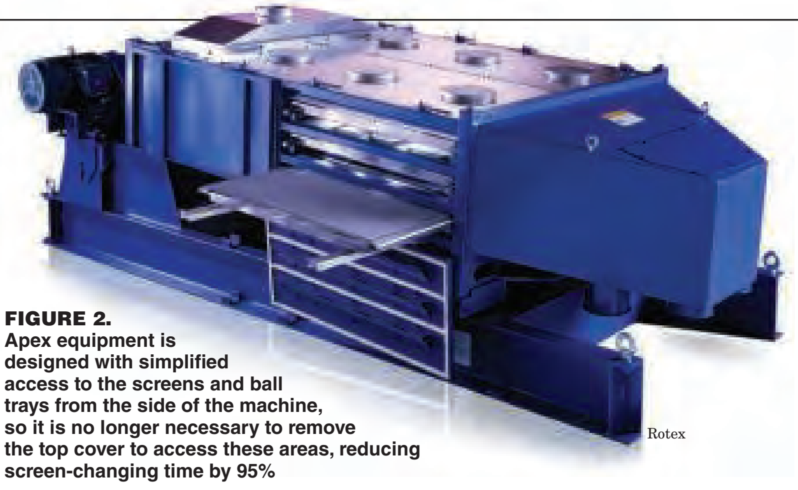


FIGURE 2. **Apex equipment is designed with simplified access to the screens and ball trays from the side of the machine, so it is no longer necessary to remove the top cover to access these areas, reducing screen-changing time by 95%**

Rotex

tional speed range of 950 to 1,450 rotations per minute, reducing wear on the separator and maximizing the life of the motor. The speed can be increased for production schedule improvements or reduced for less energy consumption and longer equipment life.

"With this design, we've moved the motor away from the vibrating areas of the machine and the bearings away from the heat of the motor, which is destructive to the bearings, so it provides longer motor and bearing life, reducing downtime," explains Bill Crone, president of Midwestern Industries. "And if you do need to replace the motor, it's a standard NEMA motor that you can buy off the shelf and put in easily, eliminating the need to keep a spare, high-priced, specialized motor in stock."

Reducing equipment maintenance isn't the only way to lower costs in this area — dust control plays a large part too. And, several manufacturers are working on ways to better control the dust associated with bulk solids. Kason Corp.'s (Millburn, N.J.) Vibroscreen circular vibratory screeners are among them. This model separates bulk solid materials from solids and slurries using a multi-plane, inertial vibration that causes particles to pass through apertures in the screen or to travel across the screen surface in controlled pathways.

"We also use a special cover on it, specialized internal equipment and a small amount of vacuum, which come together to function like a dust collector," says Brian Sirak, application engineer with Kason. "This equipment reduces area maintenance when processing materials with a lot of fines or low-density particles that are not easily separated through standard vibratory screening, because we use vented air to help remove anything lower density than the product or additional fines that may be troublesome during downstream processing."

Similarly, Russell-Finex offers the Compact 3-in-1 Sieve, which has been designed to check screen hand-fed ingredients. The bag-tipping platform with an integrated dust hood provides an ergonomic solution for operators with a comfortable height for tipping bags. The dust hood at the top reduces dust generated during sieving.

Increasing efficiency

"Every customer's wish list includes increasing efficiency and getting more capacity out of their screening equipment," says Scheper. "They're asking us to simplify the maintenance and, at the same time, optimize the equipment so they can maximize the efficiency of their screening process, and there are several ways we can do that." Among them, he says, are optimizing speed and stroke, reducing screen blinding and new control methods. Most equipment providers are finding ways to incorporate one or more of these methods into their offerings.

The Rotex Megatex XD screener was designed to maximize efficiency in high-volume applications; the unit offers a lot of screening area in a small footprint. The elliptical, linear motion accurately and efficiently handles coarse to fine separations (from 1/4 in. to 100 mesh) using equal feed distribution to all screen decks, uniform bed depth across the entire screen surface and aggressive blinding control with durable mesh-cleaning balls. Along with these features, the Megatex XD provides single screen access without the need to remove all decks. A single deck screen change can be done in 10 min., and all 12 decks can be changed in 2 h. A sleeveless brush system and discharge vent connection are also available for dust control without connecting sleeves.

Also for high volume applications, Midwestern Industries provides the MEV high-frequency screener (Figure 3). This rectangular screener uses an elliptical motion to convey material across the screening surface. Available with one to five screening decks, the unit retains material at the feed end for a longer period of time, then

FIGURE 3. Midwestern Industries' MEV high-frequency rectangular screener uses an elliptical motion to convey material across the screening surface

SCREENING EQUIPMENT SERVICE PROVIDERS

Allgaier Werk	www.allgaier.de
Kason Corp.	www.kason.com
Kemutec	www.kemutecusa.com
Midwestern Industries	www.midwesternind.com
Quadro Engineering Group	www.quadro.com
Rotex	www.rotex.com
Russell-Finex	www.russellfinex.com
Sweco	www.sweco.com
Virto-Elcan	www.virto-elcan.com

gently slopes near the discharge end, assisting the material off the screening deck and into production. This is achieved by the screener's parallel-arc configuration. Crossbars support the end-tensioned screens and create a flat screening surface to maximize screening area, while simplifying screen panel changes and allowing screen change times of 10 to 15 min.

"I don't have a pocket full of miracles, but I can often help customers increase capacity with this machine," says Crone. "In some cases, one of these machines has replaced six or eight round separators and increased throughput while using less floor space. Very few pieces of equipment can screen high volumes down as fine as this machine."

And, Russell-Finex offers the Russell Compact Sieve (Figure 4) to more efficiently eliminate oversize material in a smaller space. These vibrating screens achieve a higher throughput per unit mesh area than do conventional vibrating screens. O'Connell says they can achieve throughput rates up to 60,000 kg/h and are designed to fit neatly into existing production lines as they are less than half the height of traditional sieving machines.

Still, other equipment manufacturers are changing the motion of the machine to achieve higher capacities for their customers. Kason, for example, offers the Centri-Sifter centrifugal screener to sift, scalp, de-lump and dewater bulk solids and slurries without traditional vibration. Instead, material is fed into the feed inlet and redirected into the cylindrical sifting chamber by means of a feed screw. Rotating, helical paddles within the chamber continuously propel the material against the screen, while the resultant centrifugal force on the particles accelerates them through the apertures. These rotating paddles, which never make contact with the screen, also serve to break up soft agglomerates. Oversized particles and trash are ejected via the oversize discharge spout.

"This equipment is ideal for increasing the processing efficiency of materials that are sluggish," says Sirak. "Because as the material feeds in the paddle assembly, it turns at a specific rotational speed, allowing sluggish materials to flow inside the basket, which separates them faster than a traditional vibratory screener would. As particles are accelerated and fluidized, they tend to find the hole open-

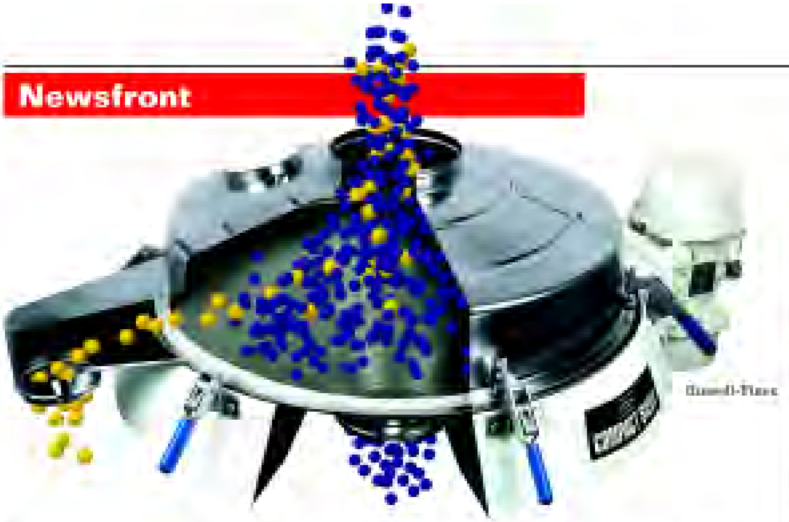


FIGURE 4. The Russell Compact Sieve removes oversized contamination and is suitable for high capacity safety screening of powders and liquid slurries

ings much easier than on a standard vibratory screener."

On a similar premise, Quadro (Ontario, Canada) offers the FlexSift. "This machine is based on centrifugal force to process chemicals and solid powders much faster and, at the same time, provide higher capacities and easier cleanability, resulting in less downtime," says Mina Ibrahim, product manager for the solids processing division with Quadro. The machine is equipped with a rotating basket which contains a perforated screen that is available in different hole sizes. Product enters the top of the equipment and falls into the basket, which spins and forces the material to the outside walls of the basket. Product passes through the holes in the screen, and impurities are left behind. This rotating action, combined with an optional custom designed spoiler arm also delumps powders without reducing the size of the particles. The spoiler arm also aids in sifting of very fine particles, typically in the 50 mesh and below range, which traditional sifting technologies have difficulty in passing through their screens. "Sifting efficiency is improved by approximately 80%," says Ibrahim. "We have seen incredibly high capacities with this machine — sometimes up to 20,000 lb/h."

In addition, the equipment offers a compact, low profile, which fits below most bulk bag unloaders and mixer discharges, allowing it to integrate easily into most systems. ■

Joy LePree

Packing must fail

For the first half of my career, I worked in a group that developed, designed and sold distillation trays. Late during the 1970s, half of that group's business disappeared — almost overnight — when structured packing replaced trays in very large ethylbenzene-styrene vacuum columns. Even the best of trays could not compete with the low pressure drops of structured packings.

In 1985, Norton Co. authored the following articles: "Distillation of Light Hydrocarbons in Packed Columns" by R. F. Strigle, Jr. and "Tower Packings Cut Olefin-Plant Energy Needs" by J.R. Sauter and W.E. Younts III. Those articles sent a shock wave through my tray group. We said, "*They want to pack everything*." We also said, "For trays to survive...*packing must fail*." For the next four years, I kept a file on global packing failures. After four years, the file included 33 cases where packings had fallen short. Approximately half of the cases regarded structured packing. Distributors and redistributors were mentioned often as were "second revamps" and "plugging" and "broken promises". There were cases where the old tray rings had been left inside revamped columns. There were identical towers that performed non-identically. There were phrases in the file like "good separation at low feedrates" and "good purity but poor recovery" and "good capacity but poor separation." There was a propylene splitter that became "infamous" in the industry. One other column had a "hot side" and a "cold side." In many of the shortfalls, the liquid-to-vapor ratios (*L/V*) were high or the surface tensions were low or the vapor densities were high. *All* of the packing vendors had experienced some troubles.

Packing partisans were perplexed but unperturbed. Important lessons were learned during the troubleshoots. Laboratory development projects yielded additional valuable revelations. FRI's membership redirected FRI's efforts. In the 1970s, 90% of FRI's major projects addressed trays and 10% addressed packings. By the 1980s, 40% addressed packings. These days, the tray/packing project breakdown at FRI is about 50/50 — and has been that way for about the last 20 years.

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

FRI's contributions to the random packing and structured packing technologies have been appreciable. The efficiencies and capacities of a wide range of random and structured packing sizes were determined. System pressures from 16 mm Hg abs to 500 psia were studied. Pre-distributors, distributors and redistributors were studied, including drip tube densities, drip tube diameters and drip tube elevations (above the top of the packings). Maldistributions were purposely created and gamma scan diagnostic techniques were refined. Cross and bayonet samplings were effected. Top-to-bottom composition data were used to study bed length effects. Efficiency humps were discovered and documented. Secrets regarding high pressure, high L/V and low surface-tension utilizations were uncovered. The impacts of reflux subcooling were studied.

Late last year, Dr. Simon Chambers, of FRI's staff, produced a 25-min training video on the use of structured packing that FRI calls "Video SP." While previewing that video this January, I recalled the 1980s history of packings. Today, packings are used easily and successfully across a large variety of applications. Vendors hate shortfalls just as much as plant operators do. Packing shortfalls, these days, are few and far between. ■

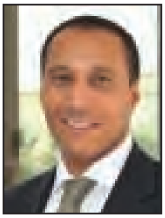
Mike Resetarits
resetarits@fri.org

WHO'S WHO


Feenan


Wallis-Lage


Reckmann


Toubia


Hu

Styron (Berwyn, Pa.), which operates plastics, rubber and latex businesses, promotes *John Feenan* to executive vice president and CFO.

Shimadzu Corp. (Columbia, Md.) names *Shuzo Maruyama* president of Shimadzu Scientific Instruments.

Black & Veatch (Kansas City, Mo.) appoints *Cindy Wallis-Lage* president of its global water business.

Bruno Reckmann is now sales manager for the business divisions of conveying and loading, palletizing and packaging at **Beumer Maschinenfabrik GmbH** (Beckun, Germany), responsible for Europe, the Middle East and Asia.

Adil Toubia becomes CEO of the Oil & Gas Division of **Siemens Energy** (Erlangen, Germany).

Robert Hu joins **The Hallstar Company** (Chicago, Ill.) as vice president of research and development.

Chicago Pneumatic (Rock Hill, S.C.) names *Todd Francis* vice president, North America.

Lanxess AG (Leverkusen, Germany) appoints *Joerg Schneider* to lead the Agro & Fine Chemicals business line of Saltigo GmbH, a supplier of custom synthesis products.

X-Rite, Inc. (Grand Rapids, Mich.), which provides color science and technology to many industries, names *Vic Stalam* senior vice president of sales and marketing. ■

Suzanne Shelley

FOCUS ON
Valves

Metso

Asahi/America

Nibco

Plast-O-Matic Valves

Fugitive emissions are minimized with this control valve

The Neles Finetrol rotary control valve (photo) can achieve ISO 15848-1 class BH fugitive-emission-type approval certification in the most demanding endurance class (CH-3; 100,000 mechanical cycles). The new design reduces health and safety risks, says the manufacturer, because leakage from gland packing can cause serious damage to personnel and to the immediate surroundings, particularly when noxious flow media are involved. The ISO approval certificate covers the full 1–10-in. size range and ASME 150 and 300 pressure classes. Quarter-turn valve design combined with live-loaded packing is accepted as the most efficient and environmentally friendly solution for all control valve applications due to its low fugitive emissions, says the company. — *Metso Corp., Helsinki, Finland*
www.metso.com

No metal parts are wetted in this plastic pressure regulator

The Series UPR Pressure Regulator (photo) features a Kynar PVDF (polyvinylidene fluoride) body, TFM convoluted diaphragm and PVDF spigots or flare connections. The valve has no wetted metals or elastomers; the metal component (one spring) is stainless steel and is isolated by an impervious barrier seal. Pressure is set by turning a plastic bolt to change the spring rate. The UPR is a normally open valve designed to reduce the inlet pressure to a pre-determined lower pressure downstream. Maximum inlet pressure is 125 psi. — *Plast-O-Matic Valves Inc., Cedar Grove, N.J.*
www.plastomatic.com

Protect pumps from flooding with this check valve

Wafer check valves are installed on the discharge side of pumps in applications such as water treatment and municipal water to prevent back-flow flooding that could seriously damage pump systems. This company's new 10- and 12-in. PVC wafer check valve's (photo) body, disc and stopper assembly are machined from solid PVC plate stock, which conforms to ASTM D1784 Cell Classification 12454A. This material was selected based on its excellent chemical resistance and mechanical properties. The wafer check valves conform to ISO 5752 face-to-face dimensions and are easily installed by slip-fitting the valve between two mating flanges. The valve body automatically centers on the mating flanges, once the stud pack is installed. The unique design of the disc and stopper permits the disc to fully open when upstream flow is present, without interfering with schedule piping and mating flanges. The valves are available in PVC with EPDM seals and no spring, as standard. Both valves operate at a maximum pressure of 90 psi and up to 120°F. — *Asahi/America, Inc., Malden, Mass.*
www.asahi-america.com

This actuator allows for increased flow capacities

The C27 actuator is the first in a new line of actuators from this company that can be coupled to any one of several body assemblies or valve-body models. The C27 delivers higher bench ranges that allow for an increase in pressure drop capacities and an in-

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

crease in flow capacities. Because the stem and yoke are shorter in the new actuator design, the valve assembly is also more compact, which means the unit will require less space when installed in a gas, oil, water, steam or corrosive-liquid transfer system, says the manufacturer. As the first in the Series, the C27 actuator has already been fitted to the company's Model 2296 (photo, p. 29) — an economical stainless-steel or bronze control valve with cryogenic capability — and the Model 987, with a slight modification of the stem length. — *Cashco Inc., Ellsworth, Kan.*
www.cashco.com


Promation Engineering


Collins Instrument


Emerson Process Management

This valve lets you know if it's improperly crimped

The new PC585-70 cast bronze ball valve (photo, p. 29) features a new design that allows a leak to occur during testing, if the press connection is not properly crimped. The new design of the O-ring with the valve allows the valve to visibly leak during testing. By designing a leak bath into the valve connection, uncrimped joints can be identified during testing, thereby preventing potential damage to the building after project completion. The ball valve features threaded-in female press-to-connect end connections with an inboard bead and interface O-ring for fast connection to the piping system. Properly applying pressure from a press-fit tool tightens the O-ring onto the tube, ensuring a clean, permanent, watertight seal in seconds, with no flame, solder or flux. The valve is designed for connection to rigid copper tubing. — *Nibco Inc., Elkhart, Ind.*
www.nibco

A plastic control valve for corrosive service

The Model 2060 (photo) is a low-cost, 2-in.-flanged plastic control valve that is designed to handle corrosive fluids. The valve features a body of either PVDF or polypropylene (PP), and an actuator/yoke of glass-filled PP, thus making it suitable for harsh fluids or corrosive environments. Depending on the application, the 2060 can be equipped with either a pneumatic positioner, a positioner with integral I/P or an electrical actuator. The new valve has a 2-in. body with 150-psi flat-faced ANSI flanges, and handles a maximum operating pressure of 300 psi at ambient (73°F) temperature, and handles fluids including hydrochloric acid, caustic, sulfuric acid and many others that would ordinarily require a more exotic (and expensive) alloy-metal valve, says the manufacturer. The valve is available with trim sizes up to $C_v = 38$, and features either all-plastic trim, all-metal trim, or a combination of exotic-alloy-metal and plastic trim. — *Collins Instrument Co., Angleton, Tex.*
www.collinsinst.com

Eliminate positioner problems with this booster

The Fisher VBL booster (photo) incorporates fixed deadband, internal soft seats and an integral bypass restriction that combine to eliminate the positioner problems typically caused by boosters without these design features, says the manufacturer. The internal soft seats yield tight shutoff to reduce unnecessary air consumption and eliminate saturation of positioner relays. The bypass restriction enables fast actuator response, and allows tuning valve response to follow slow signal changes or provide on/off control. This fine-tuning does not impact booster deadband. The booster features an aluminum body with 1/4 NPT input and 1/2 NPT connections, internal diaphragms, upper and lower valves and O-rings made of HNBR. Maximum input signal pressure is 10.3 bars (150 psi) with an input-to-output ratio fixed at 1:1. — *Emerson Process Management, Marshalltown, Iowa*
www.emersonprocess.com

A self-locking drive train makes this actuator operate smoothly

The P2-13 Series quarter-turn electric, non-spring return actuator (photo) features a rugged design for use with all ball and butterfly valves or dampers requiring higher torque outputs from 800 to 40,500 in.-lb. The Series features a self-locking hardened-steel drive train for smooth operation, mechanical end-of-travel stops and patented clutch-free manual override for single-handed positioning of the actuator. The actuator includes an integrated position indicator, two auxiliary switches, an internal low-power, anti-condensation heater and cast-aluminum, polymer-coated housing with two 3/4-in. conduit connections that are rated NEMA 4X. — *Promation Engineering, Brooksville, Fla.*
www.promationei.com

AUMA

Assured Automation

Georg Fischer Piping Systems

Save control-panel space with this three-way valve

This company's three-way PVC ball valve (photo) provides both efficiency and reduced cost. Rather than using two two-way automated valves to control the flow of liquids, a single three-way valve does the job with fewer components and lower cost, because there is no need to purchase and install multiple actuators and solenoids, which saves I/O space in the control panel. A single three-way valve eliminates extra overhead and installation time — and money, says the manufacturer. The company has added an online configurator for the PTP Series three-way PVC ball valve to make it quick and easy for engineers to specify the requirements. — *Assured Automation, Clark, N.J.*

www.assuredautomation.com

A single-mode FO interface extends the range to 15 km

Expanding demand for the use of fiber optics (FO) as a field data-transfer solution has led to this company's introduction of a single-mode FO interface (photo) capable of supporting automation solutions with a range of up to 15 km between field devices — significantly extended beyond the 2.5 km supported by established multimode FO technology. An enlarged actuator terminal compartment simplifies cable connections and the new FO solution can be configured as required. Should the optical signal fall short of its required level, an alarm is transmitted to the DCS via fieldbus. FO cable checks are integrated into the comprehensive self-monitoring capability of the company's generation-two actuator controls. — *AUMA Riester GmbH & Co. KG, Mülheim, Germany*

www.auma.com

A battery powered controller for remote locations

Last December, the VC10 Valve Controller (photo, p. 32) was added to this company's Accutech wireless-sensor-network product line. A battery-powered wireless field device, the VC10 is used to control pneumatic valves in

Tyco Flow Control

Schneider Electric, Telemetry & Remote Scada Solutions

GEMÜ Gebr. Müller Apparatebau

hazardous locations. Using a patent-pending technology called Progressive Pulse Control (PPC), the VC10 is suited for operation of pneumatic valves in a wide range of upstream oil-and-gas applications. Coupled with the power-management technology, the VC10 is capable of operating in the field autonomously for over 50,000 cycles, which equates to years of maintenance-free operation, says the manufacturer. Included with the VC10 are two digital inputs, the first configured as a counter for use in plunger arrival systems, and the second for use with any discrete signal. An integrated pressure sensor is incorporated as a feedback mechanism in the PPC circuit and as a useful diagnostic tool for wellhead operators. — *Schneider Electric, Telemetry & Remote Scada Solutions, Kanata, Ontario, Canada*
www.controlmicrosystems.com

Longterm stability ensured with this new check valve

This company's new generation of check valves (photo, p. 31) features a hydrodynamically optimized valve cone, which minimizes the pressure loss while increasing flow by 25% compared to the previous generation. It is practically impossible for the valve cone to jam anymore since the cone is double guided, thus process stability is ensured. Another positive effect of the new cone contour is that the valve can optionally be equipped with a return spring, and thus implemented in completely new applications. When equipped with a return spring, the check valve can be installed in nearly any position, horizontal or vertical. The spring is available in three different materials: stainless steel (V2A/304), Nimonic90 and with Halar (ECTFE)-coated stainless steel. The seal profile of the check valve has also been optimized, so, together with the patented cone design, 100% leak-tightness is guaranteed, says the manufacturer. — *Georg Fischer Piping Systems Ltd., Schaffhausen, Switzerland*
www.piping.georgfischer.com

This ball valve has a self-relieving seat for added protection

This company recently launched a new KTM Unibody EB700 Series ball valve (photo). Designed and certified to meet the standards and service requirements of the petrochemical, chemical and oil-and-gas industries, the KTM Unibody EB700 Series complements the company's existing OM2 full-bore ball valve, and extends the KTM range. The one-piece, cast body minimizes potential leak paths, making it safer and more environmentally friendly than slip-valve designs, says the manufacturer. The EB700 Series features a PTFE/PFA copolymer "E" seat similar to the OM2 (EB11/12) Series. The valves in sizes above DN 25 (NPS 1) also provide an additional safety feature, incorporating cavity self-relieving seats to relieve potential ball-cavity overpressure when the valve is in the closed position. The KTM Unibody valves are available in dual-certified carbon steel to ASTM A216 WCB/WCC and in stainless steel, certified to ASTM A315 CF8M. Standard trim material is 316 stainless steel. — *Tyco Flow Control, Princeton, N.J.*
www.tycoflowcontrol.com

Compact diaphragm valves are available in a variety of plastics

The new R690 and R677 2/2-way plastic diaphragm valves (photo) are small, compact and lightweight, and are designed so that combinations of several nominal sizes can be installed on the same mounting height plane. For installation, the valves are supplied in all standard connections for the different international standards. The redesigned, flow-optimized valve bodies provide the same high flowrates — in some cases even higher — as the previous models, while being competitively priced, says the manufacturer. Depending on the valve design, they work reliably at temperatures from –20 to 80°C and at pressures of up to 10 bars. The product line comprises nominal sizes from DN 15 to 100. In addition to standard optical position indicators, optional features include: electrical position indicators, positioners or process controllers; manual overrides; pilot valves; seal adjusters and stroke limiters. Valve bodies are available in a variety of plastics (PVC-U, PP, ABS and more), and a wide range of seal, materials (EPDM, PTFE, FPM and NBR). — *GEMÜ Gebr. Müller Apparatebau GmbH & Co. KG, Ingelfingen-Criesbach, Germany*
www.gemue.de ■

Gerald Ondrey

Europe special advertising section
March 2012
CHEMICAL ENGINEERING
Access Intelligence

Exhibition time for European engineers

Demonstrating a single-use stirred-tank bioreactor at ACHEMA 2009. Bioengineering and renewable energy technologies promise an even stronger showing at this year's ACHEMA

Inside

The Euro may be in turmoil, but the German-speaking nations at the heart of Europe's equipment manufacturing sector are doing comparatively well, as the size of this year's Europe special advertising section confirms. In Austria, Switzerland and especially Germany, vendors are busy building the equipment – and supplying the complete plants – for which they are known worldwide. And this year Germany will be hosting several giant exhibitions and conferences of interest to the chemical process industries (CPI).

First on the schedule comes **Anuga FoodTec** (www.anugafoodtec.com), which takes place in Cologne, 27–30 March. This international trade fair for food and drink technology takes place every two years, and boasts an exhibition area of 115,000 m². In 2009 it attracted 1,210 exhibitors, of whom nearly half came from outside Germany. According to joint organizers Koelnmesse GmbH and the German Agricultural Society (DLG), this year's event is likely to be more than 16% larger. Three principal exhibition themes – food processing, food packaging, and food safety – will be backed up by 27 specialist forums and a conference program.

Next is **IFAT ENTSORGA** (www.ifat.de) over the week 7–11 May. The world's leading trade fair for water, sewage, waste and raw materials management is organized by Messe München GmbH and takes place in Munich every two years. In 2010 it attracted 2,730 exhibitors, of whom over one-third were from outside Germany, and covered a floor area of 200,000 m². Technologies of interest to chemical engineers at IFAT ENTSORGA include water and wastewater treatment, municipal refuse recycling, waste-to-energy processes, treatment of contaminated land, flue gas scrubbing, and other air pollution abatement techniques.

Then from 18–22 June comes the big one as far as the CPI is concerned: the massive three-yearly **ACHEMA** exhibition and congress (www.achema.de) in Frankfurt am Main. This 30th ACHEMA is expected to attract more than 3,700 exhibitors and 173,000 visitors. As our report by organizer DECHEMA eV (Frankfurt, Germany; www.dechema.de) on the next page explains, energy and resources will be two of the topics generating the biggest buzz. A congress program of more than 900 presentations allows visitors to stay up to date on the full range of chemical engineering topics.

Many of the companies showcased in the following pages will be exhibiting at one of these three events. Readers of CE are urged to check them out on their home ground. ■

Water treatment discussions at IFAT ENTSORGA in 2010

ACHEMA: Showcase for the world

Dr. Kathrin Rübberdt of organizer DECHEMA e.V. explains the global focus of the world's largest event for the CPI

In the run-up to ACHEMA one thing is already evident: the organizers and the exhibitors are unanimously optimistic about the world's biggest fair for chemical engineering, biotechnology and environmental protection, which will take place from 18–22 June 2012 in Frankfurt am Main, Germany.

Current economic outlooks may in parts be inconsistent due to contradictory developments depending on industry and geography. But overall, the chemical and the plant engineering industries are looking back on two very strong years, and the perspectives for the process industries are far less cloudy than some of the professional pessimists are claiming. According to the American Chemistry Council, the U.S. chemical industry will experience moderate production increases, and the European Chemical Industry Council expects growth to strengthen in 2012. Apart from production growth, drivers such as increasing demand for energy-efficient solutions, new security requirements, and general process innovation are influencing the industry and its suppliers, and promise positive development in the years to come.

ACHEMA as the global hub for the process industries reflects these trends. The figures speak for themselves: the exhibition groups Instrumentation, Control and Automation Techniques and Pharmaceutical, Packaging and Storage Techniques show clear growth over 2009, when a total of 3,767 exhibitors and over 173,000 visitors was recorded. The share of international exhibitors is currently around 47%; the increases from India and China are particularly striking, but also those from other countries like Turkey and South Korea.

The major hot topics at ACHEMA 2012 are energy and resources. New energy storage technologies, particularly energy-saving plants, are highly relevant to the energy-intensive chemical industry. At the same time, the industry plays an important role in developing new storage materials for batteries and heat storage, both of which are essential for the continued growth of renewable energy. The global markets are hungry for solutions, and we can expect an immense innovation push.

The Special Show "Innovative Energy Carriers and Storage" at ACHEMA 2012 puts the latest developments in energy storage and transfer on display. Chemical energy storage, fuel cells, photovoltaics and solar

Solar heat and power will be among the renewable energy technologies highlighted at ACHEMA

chemical processes are all covered, as well as new ideas in e-mobility, innovative battery technologies, and the use of hydrogen as an energy carrier. Dicussing these topics within the wider context of ACHEMA, where all aspects of chemical processing and biotechnology are on display, creates outstanding opportunities for integration and synergy.

More traditional areas are also on the upswing. In instrumentation and control, for instance, the German industry association ZVEI expects growth of 15% for 2011 and a continuing positive outlook in 2012. This reflects optimism that widespread across both geography and industries, with the energy-related industries leading the way. In the chemical industry, increasing levels of process integration and the new possibilities of inline and online analytics are the main drivers for instrumentation and control. Wireless remains a major topic, while IT security awareness is also increasing in the light of recent hacking attacks on several organizations.

Similarly, the increasing use of renewable resources coupled with the application of biotechnological processes is generating new requirements for equipment and technology. Biorefineries, bio-based products,

Continued on page 32I-4...

Membranes for wastewater

German hospital opens a wastewater treatment plant based on MBR technology from MICRODYN-NADIR

The new treatment plant at the Marienhospital, Gelsenkirchen

With environmental regulations becoming increasingly stringent, membrane bioreactor (MBR) technology with its high-quality effluent is a good fit for wastewater treatment – as shown recently at the Marienhospital in Gelsenkirchen, Germany. Commissioned in July 2011, the hospital's wastewater treatment plant is one of the first in Europe to focus on eliminating micro-pollutants such as pharmaceutical residues and radio-opaque substances. It was built in the context of an EU-supported project named PILLS (Pharmaceutical Input and Elimination from Local Sources) under the aegis of the Emschergenossenschaft. The Marienhospital treats around 75,000 patients every year and generates up to 200 m^3/d of effluent. Until now, this wastewater has been discharged untreated into a nearby river. The new treatment plant uses mechanical and biological clarification, ultrafiltration and other processes to improve the purity of the river.

The ultrafiltration stage is based on three submerged BC400 MBR modules from **MICRODYN-NADIR**, installed downstream of the aeration tank. With a total membrane area of 1,200 m^2, these remove microscopic particles and bacteria from the wastewater. Following ultrafiltration, ozone is added to oxidize the micro-pollutants into nonhazardous substances. Micro-pollutants are also adsorbed onto pulverized activated carbon.

ACHEMA Hall 5.0 E61
IFAT ENTSORGA Hall A2 303
www.microdyn-nadir.de

Experts in thermal separation

Thin-film evaporators from GIG Karasek increase process quality with low environmental impact

GIG Karasek supplies plants and key equipment for thermal separations: wiped film evaporation, molecular distillation and rectification, and specialist equipment for the life sciences.

The lean organizational structure of this family-run Austrian company means that the customer has only one partner for basic engineering, fabrication, installation, and commissioning. Key equipment is manufactured in the firm's own workshops under strict quality control. GIG Karasek's headquarters are located near Vienna, where the company also operates a test and development center for evaporation and thermal separation technology.

At ACHEMA, GIG Karasek will be demonstrating its proven thermal wiped-film dryer technology, which has applications from food to chemicals. The special rotor technology is used to create thin-film evaporators with inside diameters of 80 in. or more. Such large evaporators can increase profit margins by raising process capacity and improving purity. Advantages include:

GIG Karasek's proven thermal wiped-film dryer technology

- low environmental impact;
- no emissions (smell, gas, dust, or noise);
- massive construction and low maintenance;
- small footprint;
- continuous operation;
- gentle product handling thanks to the short residence time.

ACHEMA Hall 4.0 A68
IFAT ENTSORGA Hall A4 110
www.gigkarasek.at

...Continued from page 32I-2

renewable resources, industrial biotechnology – the bio-based economy is not a buzzword but a living reality. Not only is a new biotechnology industry with new players entering the field, but established industries like the chemical and other process industries are undergoing a rapid transformation. New raw materials and innovative biotechnological processes call in turn for adjustments in equipment, MSR and automation technologies and many more.

ACHEMA 2012 reflects the trend in its platform "bio-basedWorld at ACHEMA". This offers the unique chance for established industry players, new market entrants, scientists and investors to meet in one place and discuss state-of-the-art technologies and products. The new concept acknowledges the fact that biotechnology and renewables play a part in all of ACHEMA's exhibition groups.

Start-ups, SMEs, and entrepreneurs will find support and contacts at the BIOCHEM Accelerator Forum. Organized by the partners of the EU's BIOCHEM project, dedicated venture capital days, a business plan competition and entrepreneurial teaching classes address the special needs of young companies trying to establish a presence in the market with bio-based products. Together with technology transfer days and a partnering tool, ACHEMA offers an all-round package and acts as an incubator for bio-based industries. A two-day conference on "European Innovation Partnership" brings together players from politics, industry and academia to discuss practical aspects of implementing the bioeconomy.

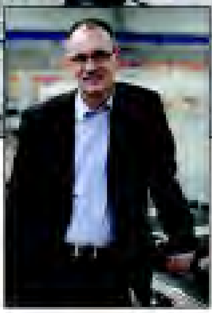
The first-ever ACHEMA Partnering Platform enables exhibitors and attendees to selectively identify potential cooperation partners, initiate contacts and schedule meetings well in advance of the event. It is open to all exhibitors and visitors within and beyond the bio-basedWorld. Exhibitors and visitors can register two months in advance of the event. The system matches cooperation requests with offers to create an individual meeting schedule; meetings may take place either at exhibition stands or in a dedicated partnering area.

ACHEMA in its breadth and depth represents technological developments that address urgent economic and societal challenges, from sustainable production of goods to mobility, security, and the satisfaction of the basic needs of people worldwide. This global exchange forum offers a unique opportunity to work together on innovative solutions. It is a showcase not just for European industries, but for the world. ■

www.achema.de

Efficiency from custom intralogistics solutions

BEUMER ensures smooth materials handling and warehouse automation



The BEUMER robotpac range palletizes and depalletizes different items using gripper elements and tools developed specifically for each task. (Right) Dr. Christoph Beumer, Managing Partner and Chairman of the Board of Directors

The Beckum-based **BEUMER Group**, with affiliations around the globe, works intensively with chemical manufacturers to develop products and system solutions that meet the complex demands of the industry. The family-run company's product range includes bagging, palletizing, load securing and complete warehouse management systems. These cutting-edge intralogistics solutions ensure maximum efficiency.

Founded in 1935 in Beckum by Bernhard Beumer, the BEUMER Group has a clear philosophy: "Our objective is not short-term gain, but long-term success." Thanks in part to the acquisition of a number of companies, the group now has approximately 3,000 employees and annual sales of about €450 million.

As a system provider, BEUMER offers solutions for the entire process chain in the chemical industry. This includes not only packaging machines and palletizers, but also a warehouse management system (WMS) with an interface to the customer's higher-level ERP system. The WMS integrates warehouse management and material flow control, permitting users to match their production processes and warehousing to current demands, and avoiding mix-ups in warehousing and shipping. Processes in the warehouse are more transparent and efficient for all concerned.

High-performance palletizers in a wide range of types form secure load units for both special and bulk products in the chemical, food, and animal feedstuffs industries. BEUMER robotpac machines (photo) use gripper elements and tools to palletize and depalletize many kinds of goods. BEUMER stretch hood packaging machines provide the necessary protection for palletized goods in storage and transport. The stretch hood film which secures the package on the pallet is very sturdy because it is kept under continuous tension in the horizontal and vertical direction. BEUMER delivers everything from a single source, thus ensuring quick installation and safe, successful implementation.

ACHEMA Hall 3.0 F50
www.beumer.com

Key technologies for compressors and drives

HOERBIGER presents new monitoring and maintenance solutions for reciprocating compressors, plus developments in valve actuators and positioners

The highly modular RecipCOM system offers sophisticated monitoring, protection, analyses and optimization of reciprocating compressors – with SIL certified reliability

At ACHEMA this year, **HOERBIGER** will present the latest generation of its RecipCOM system and the production version of an electrohydraulic valve actuator.

RecipCOM is a monitoring, protection, and diagnostic system for reciprocating compressors. With its new modular and scalable structure, HOERBIGER's latest RecipCOM can also provide excellent machinery protection for older compressors – a fully customizable and cost-effective solution.

The sophisticated RecipCOM diagnostic software continuously informs the operator about the current status of the compressor, making any variations in performance and efficiency immediately visible. Detailed signal recording and trend calculations support decision-making and fault analysis. With the option to shut down the compressor within a few revolutions, RecipCOM can also prevent severe damage.

The new production version of HOERBIGER's electrohydraulic valve actuator combines the sensitivity of electric drive technology with the power density and dynamic response of a hydraulic system. This innovative actuator is operated electrically through a simple interface, and works autonomously without the need for external hydraulic lines.

The electro-hydraulic valve actuator combines the advantages of electric and hydraulic drives. A pressure-resistant housing makes it suitable for use in hazardous atmospheres

Also on show will be HOERBIGER's new compressor "Upgrade and Revamp" service: innovative and proven components and the most advanced maintenance technology to make older compressors fit for the future. Its four fundamentals are lifetime extension, troubleshooting, external process changes, and energy optimization. The CP valve and the BCD packing ring are two high-tech components for the efficient and environmentally friendly operation of reciprocating compressors.

HOERBIGER will be unveiling developments in industrial valve automation, in particular piezo-pneumatic pressure regulator modules which, with newly developed interfaces and unparalleled low power consumption, open up new perspectives for manufacturers of valve positioners.

ACHEMA Hall 8.0 D28
www.hoerbiger.com

Intelligent valve and actuator solutions

ARCA Regler GmbH, the parent company of ARCA Flow Group, maintains its position as a leader in control valve technology

For more than 90 years **ARCA Regler** has concentrated on the development, production, sales and service of pneumatic and electrically-activated control valves. Continuous product development and many patents have resulted in ARCA's being honored as one of the 100 most innovative firms in Germany.

Von Rohr Valves and WEKA Cryogenics – both based in Switzerland – as well as ARTES Valve & Service and FELUWA Pumps in Germany are the other companies of the ARCA Flow Group.

Production plants and joint ventures in India, China and Korea are backed up by a global sales network, providing excellent technical advice and lifetime service.

In industrial process control, ARCA has established a new standard with the modular ECOTROL control valve system. In sizes from ½ in. (DN 15) to 24 in. (DN 600) and pressure rating up to Class 1500 (PN 250), ECOTROL with the unique SWS quick-change system offers a solution for every application.

All ARCA control valves are delivered as a ready-to-install package consisting of control valve, pneumatic actuator, and pre-configured ARCAPRO intelligent valve positioner.

Starting with the well-proven direct positioner interface with integral air tubing and the patented ARCAPLUG position feedback system, ARCA always has been a leader in valve actuator technology, especially when it comes to actuator/positioner mounting interfacing and positioner integration.

Nowadays ARCA actuators can be equipped with the OPOS interface, a further development of the vendor-independent VDI-3847 positioner mounting standard (photo, right). Besides standard features such as lower mounting costs, reduced spare parts inventory and increased reliability, the OPOS interface provides the ability to safely replace the positioner during operation by means of integrated interlocking. Furthermore, the integrated instrument air purge of the spring chamber provides long lifetime and better reliability through enhanced protection of the actuator internals.

ECOTROL valve with OPOS interface

An exciting new development is ARCASMART – as the first actuator with a fully integrated intelligent positioner, it is the obvious choice for demanding applications. The sturdy yet elegant design, which includes flushing of the entire internal space with vent air, ensures that ARCASMART covers a wide application spectrum from hygienic processing up to extreme environmental conditions. All adjustments and diagnostic parameters are already factory-set to create a perfect match for the actuator size, valve configuration and application.

ACHEMA Hall 8.0 G94
www.arca-valve.com

Sustainable, innovative plants and technologies

Outotec is a world leader in technologies for minerals and metals processing, and also operates in water treatment and alternative energy

Outotec develops and provides technology solutions for the sustainable use of Earth's natural resources. Thanks to their energy efficiency, Outotec technologies are frequently rated as BAT (best available technology) and also support initiatives to reduce emissions.

As a global leader in minerals and metals processing, Outotec has developed innovative technologies which add up to more than 2,000 installations around the world. The firm also offers innovative solutions for industrial water treatment and alternative energy. Outotec's solutions include proprietary technology, feasibility studies, basic and detail engineering, process equipment, automation, project implementation and life cycle services.

With a history of over 100 years from two major metal companies, Outokumpu and Lurgi Metallurgie, Outotec has become a major force in the global mining and metallurgical industry, in both the ferrous and non-ferrous segments. Outotec's engineering expertise, innovative plant and equipment designs and strong R&D capabilities have translated into superior industry benchmark technologies and solutions benefitting customers worldwide.

Collaboration with Outotec provides reliability and benefits by:

- guaranteeing a license to operate;
- ensuring sustainability through the latest and best technology;

The world's largest sulfuric acid production complex at Ma'aden, Saudi Arabia

- increasing profitability through customized solutions;
- saving time and money thanks to fast and reliable project implementation;
- including performance guarantees; and
- increasing availability, maintainability and safety of operations

Outotec professionals incorporate sustainability into every project they work on, with benefits to customers including more product from a given amount of raw material; safe working environment; less energy and water consumed; less waste and emissions; and lower operating costs.

ACHEMA Hall 5 C62 and Hall 9 E70
IFAT ENTSORGA Hall B3 132
www.outotec.com

Specialists in thin-film separation technology

Buss-SMS-Canzler has decades of experience in thermal separation

Buss-SMS-Canzler is one of the world's leading suppliers of thermal separation technology for difficult-to-handle substances and mixtures.

The company is a specialist in thin-film technology, providing technical engineering solutions based on decades of experience accumulated by the Luwa, SMS, Buss and Canzler companies. As a modern and internationally active company, Buss-SMS-Canzler develops and manufactures systems and equipment in the fields of evaporation, drying, high-viscosity and membrane technology.

The company also manufactures special equipment, for example made out of copper and copper alloys, and is active in the nuclear industry. Supported by a comprehensively equipped test centre with 20 pilot systems, the employees – more than 240 strong – develop customized and economical solutions for the process engineering requirements of customers. These solutions have been trusted for many years by renowned global companies, in areas which include plastics, fibers, polymers, specialty chemicals, agrochemicals, oleo- and petrochemicals, fine and basic chemicals, foodstuffs, pharmaceuticals, environmental solutions and energy.

Buss-SMS-Canzler Short Path Evaporator with inductive heating

One of the main products of Buss-SMS-Canzler is the Short Path Evaporator. With its internal condenser this is designed to master demanding thermal separation tasks. The combination of evaporation and condensation in extreme proximity allows the Short Path Evaporator to operate at a vacuum down to 0.001 mbar (a). This allows it to operate in specialized fields including molecular distillation, evaporation, concentration and degassing of heat-sensitive and high-boiling products.

ACHEMA Hall 4.0 B24
www.sms-vt.com

Liquid fuel from the sun

Süd-Chemie's sunliquid is a cellulosic ethanol for biofuels or green chemistry

The sunliquid demonstration plant in Straubing, Germany, in January 2012; startup is due in March this year

Süd-Chemie, a member of the Clariant Group, has set a strategic focus on the development of processes for the sustainable production of bio-based chemicals and biofuels. The conversion of lignocellulosic feedstock such as agricultural residues is of particular interest, says the company. The sunliquid technology developed by Süd-Chemie offers a fully integrated, turnkey, full-scale process for the economic production of cellulosic ethanol from residues like cereal straw, corn stover, bagasse, or other lignocellulosic feedstock. It features technological innovations covering the complete conversion chain to ensure highest yields at minimum costs.

After pretreatment, the feedstock is treated with a highly optimized set of enzymes, specific to the particular raw material and the corresponding process conditions. The enzymes are produced process-integrated on site using a small quantity of pretreated feedstock as the substrate, thus minimizing enzyme costs and avoiding dependence on third-party enzyme suppliers. After saccharification, solids are separated for use as a process fuel and the sugar-rich liquid hydrolysate enters ethanol fermentation. A proprietary, optimized fermentation organism converts all C_5 and C_6 sugars simultaneously into ethanol in a one-pot reaction yielding about 50% more ethanol than C_6 fermentation alone. Finally, an innovative ethanol purification method using Süd-Chemie technology and proprietary material saves up to 50% in energy compared to standard distillation technology. Energy derived from byproducts such as lignin meets the entire electricity and heat demand of the process, so the resulting ethanol achieves greenhouse gas reductions of close to 100%.

In July 2011, Süd-Chemie started constructing a demonstration plant to confirm the feasibility of the sunliquid technology at industrial scale. The plant is expected to be operational in March 2012, producing up to 1,000 t/y of cellulosic ethanol.

In addition to its potential in greening transport, cellulosic ethanol is a valuable raw material for the chemical industry, for instance for the production of green polyethylene. The sunliquid technology opens up a second-generation sugar platform that can yield green products like organic acids, green solvents, higher alcohols, aromatics and their derivates as specialty and bulk chemicals which can be further converted into bio-based products.

ACHEMA Hall 9.2 D38
www.sunliquid.com

Engineering with ideas

ThyssenKrupp Uhde works hard to maintain a leading position in plant engineering and construction – its international outlook and advanced technologies are key

With more than 2,000 plants to its credit, **ThyssenKrupp Uhde** is one of the world's leading engineering companies in the design and construction of chemical, refining and other industrial plants. The company has subsidiaries and associates across the globe, and over 5,600 employees. Activities include fertilizers, electrolysis, gas technologies, gasification, refining, organic intermediates, polymers, synthetic fibers, coke and high-pressure technologies. Customers receive not only cost-effective high-tech plant construction and the entire range of services associated with an EPC contractor but also comprehensive service packages.

In the international plant construction industry, it is essential for companies to provide first-class processes which guarantee industrial plant operators the best quality and economy. To meet these demands ThyssenKrupp Uhde is always looking to boost its technology portfolio with innovative new processes.

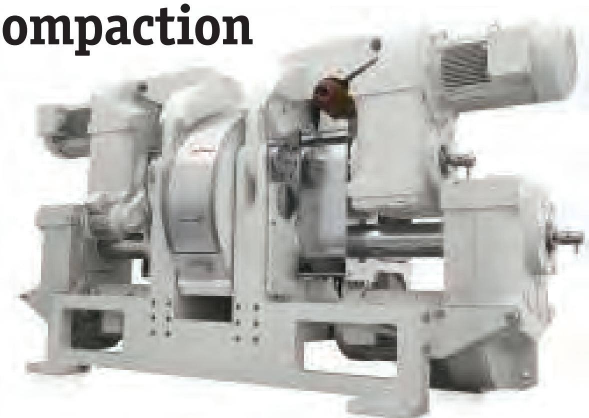
The company is also increasing its on-site competence through subsidiaries and partnerships to keep up with the increasing number of customers on the world market. These affiliates and associates abroad work to the same quality standards as the head office in Dortmund, ensuring excellent quality irrespective of location. ThyssenKrupp Uhde's various central divisions provide additional services including selecting plant location, arranging finance, negotiating with authorities, plant management, maintenance, safety analyses, safety technology, operator training, and project management.

ThyssenKrupp Uhde has built a 3,500 t/day urea plant for Yara in Sluiskil, Netherlands

ACHEMA Hall 9.1 B4
www.uhde.eu

Technology leader in dry compaction

Alexanderwerk champions a cost-effective granulation process requiring no binders



Machines from Alexanderwerk's PP series are perfect for the economic compaction of raw materials

Customers of **Alexanderwerk** operate on every continent and at all sizes of business, from multinational corporations to small private companies. Their dry compaction applications are equally diverse, and can be found in the pharmaceutical, nutraceutical, food and chemical industries, among other sectors.

Projects undertaken by the firm vary from a single stand-alone machine or production unit to a fully integrated turnkey solution. With over 1,200 installed machines in active operation, Alexanderwerk provides responsive and proactive process and technical support to customers around the globe.

The company's technology centre, located in Remscheid, Germany, is purpose-built to seek out process and technical solutions to customers' challenges. Partnerships with several universities across the world ensure an academic foundation for the design and development of equipment as well as future research and process development.

Based on its equipment, large installed base, customer satisfaction, and track record of innovations and patents, it is therefore no surprise that Alexanderwerk and many of its customers consider Alexanderwerk to be the market and technology leader in dry compaction.

Dry compaction, also referred to as direct compaction, is an economical continuous process which yields a high-quality granular product. No binding agents or liquids are required; particle adhesion is achieved purely mechanically, through the application of high pressures. The more traditional wet granulation processes requires an additional drying step, which is not needed with dry compaction. Low energy consumption and low environmental exposure are positive attributes of dry compaction technology.

Alexanderwerk's dry compaction technology is developed with full input from customers. The typical Alexanderwerk horizontal product feed ensures controlled product supply to the compaction rollers, while the vertical roller arrangement allows complete capture of leakage from the uncompacted side.

ACHEMA Hall 6.0 A76
www.alexanderwerk.com

Tailor-made valves

OHL Gutermuth makes specialist butterfly valves for the world's biggest projects

Valve manufacturer **OHL Gutermuth** offers a broad range of butterfly valves for both shut-off and control duties, plus special types, custom designs and accessories. Nominal diameters are up to DN 4000, with pressure ratings of 200 bar and more, for temperatures from –196°C to 1300°C. The firm has offered triple-offset butterfly valves for 20 years.

The firm traces its origins back to 1867. "Providing individual advice and consulting to our customers right from the start is at the centre of our efforts," explains managing partner Wolfgang Röhrig.

The Altenstadt-based company invests heavily in quality assurance, with certification to ISO 9001:2008 and Module H of the EU's Pressure Equipment Directive. All products are also certified under the Russian GOST and RTN standards and licensed for use by Gazprom. The company has operated a sales office in Beijing since 2007, and one in Moscow since 2011.

"In the past 40 years we have supplied customized valves for more than 130 gas purification plants, among them the largest in the world, in Europe, Russia, Kazakhstan, Turkmenistan, India, China, the Middle East and America", says Röhrig.

Recent projects include 220-ton valves for desulfurization plants in Iran, valves for the world's largest solar power stations, for the German and French navies, and for a 170 m-long mega-yacht belonging to Russian oil billionaire Roman Abramovitch.

ACHEMA Hall 8.0 C93
www.ohl-gutermuth.de

Controllable agitators

New electric agitators from sera are well-matched to the firm's dosing equipment

Controllable electric agitators from **Seybert & Rahier GmbH** (**sera**) (photo) are designed for use with sera's

CTD dosing systems with tank volumes in the range 100–1,000 l. They are available in a number of different configurations, including two different materials of construction for the agitator shaft and the mixing element itself.

The highlight of the new type MU agitators is their optional control electronics, adapted from sera's proven dosing pump control systems. As well as manual control, there are three automatic modes: speed control, intermittent timed operation, and an adjustable overrun time. For maximum effectiveness, the agitator controllers communicate with the rest of the sera dosing system and the plant's central control system.

ACHEMA Hall 8 K63
www.sera-web.com

ACHEMA actuator advancements

AUMA is a global supplier of modular electric actuators for the chemical process industries

Enhanced corrosion protection and asset management capability are highlighted by AUMA at ACHEMA

AUMA, the established manufacturer and innovator of modular electric actuators with expertise in the chemical process industries, will showcase its latest developments in valve automation at ACHEMA.

The Generation.2 series of actuators and gearboxes will be a key feature of the stand. The range is AUMA's most significant advancement in valve control technology since it introduced modular actuators in 1976. Fully compatible with previous products, Generation.2 boasts enhancements including improved positioning accuracy, output speed range and longer life.

Asset management capability is a key feature. With the Generation.2 product range, field devices can be integrated into asset management systems. Actuator-specific service conditions and limits can be monitored, and events recorded according to NE 107 categories to help prevent actuator failures and downtime.

Latest news includes a new two-layer powder coating process suitable for challenging environments such as those found in the chemical sector.

AUMA devices aid automation of plants in the chemical, water and wastewater treatment, power, refinery and tank farm industries. AUMA employs 2,000 people worldwide.

ACHEMA Hall 8.0 C23
www.auma.com

Drums are not just for storage

Müller's stainless steel drums and containers form an integral part of the process

Within the extensive Müller range is a stainless steel drum or container suitable for every task – from just 0.1 l right up to 1,500 l, in various diameters, material qualities, and surface finishes.

The Müller drum is the basic module in an intelligent system: at the drop of a hat a drum used for storage or transportation becomes a process vessel meeting all the requirements of present-day production.

For trouble-free and versatile manufacturing, the Müller system enables users to add to their drums items such as hoppers, dryer inserts, discharge aids, mixing hoods and sieves. The system is also compatible with all process interfaces: drum docking, dust-free

Just some of Müller's huge container range

filling, handling equipment, and emptying at the production unit. All components are harmonized with each other to form a modular system, and are interchangeable. And, because the Müller system is so flexible, drum filling quantities or storage volumes can be adapted to suit customers' individual manufacturing needs. This means that differing flow, mixing or chemical properties do not necessitate using dozens of different containers, simply the right combination of system modules. Standard sizes are available ex stock.

ACHEMA Hall 3.1 A75
www.mueller-gmbh.com

Compact, lightweight, and multifunctional

GEMÜ multifunctional plastic multi-port valve blocks meet all application requirements in the smallest of spaces

Compact valve solutions save space and installation time and offer considerable cost advantage. Multifunctional plastic multi-port valve blocks meet all application requirements for liquids and gases in the smallest of spaces. Small, lightweight yet efficient plastic diaphragm valve solutions from **GEMÜ**, the German specialist in valves, measurement and control systems, enable compact, safe and cost-efficient plant design meeting today's needs.

The space-saving multi-port valve blocks in particular have a major advantage over conventional solutions. Due to their individual design, they can perform a range of different functions in the most confined spaces, such as mixing, dividing, diverting, draining, feeding and cleaning – all in one block. Safety and control functions, sensors, filters, and non-return valves can all be added.

Intelligently designed, multi-port valve blocks form the basis for compact plant components with high functionality. Block valve solutions simplify complex piping systems considerably, largely eliminating the need for additional adapters and molded parts. Standard connection types ensure quick and simple installation.

GEMÜ compact, lightweight multi-port valves are suitable for a wide range of applications in various industrial sectors. Applications include chemical processing, environmental protection, surface finishing, coating and electroplating, municipal and industrial water treatment, and power plants. Even when it comes to sensitive processes and systems, such as reverse osmosis plants, neutralization, swimming pools with microfiltration systems, multi-port valves are a cost-effective alternative to conventional valves.

GEMÜ multi-port valve block

Plastic multi-port valve blocks ensure high flowrates and, depending on specification, operate reliably at temperatures from –20°C to +80°C and pressures up to 10 bar. They are highly resistant to corrosive media. In addition to valves, GEMÜ offers a comprehensive range of accessories including controllers, flowmeters, stroke limiters and customized sensors, all of which can be integrated into multi-port valve blocks.

ACHEMA Hall 8.0 F4
IFAT ENTSORGA Hall A4 530
Anuga FoodTec Hall 05.1 C059
www.gemu-group.com

Keeping solar power at its peak

GEA Wiegand technology regenerates heat transfer fluid needed to keep solar thermal power stations running

In a solar thermal power plant based on the parabolic trough principle, curved mirrors focus energy from the sun's rays onto pipes carrying heat transfer fluid. As it circulates through the pipes, the fluid absorbs solar energy which it transfers to a steam generator. The resulting steam is used to drive a turbine to generate electricity, just as in a conventional power plant. If thermal storage is integrated into the system, the plant can even continue to produce power even after sunset.

The parabolic trough design requires the heat transfer fluid to operate at temperatures up to 400°C. Such an extreme thermal load causes degradation of the fluid, which therefore requires regeneration at scheduled intervals. **GEA Wiegand** has developed a fully automatic distillation plant which is now being used for the first time at three Spanish solar thermal power stations. Compared to previous distillation plants, the GEA Wiegand design is characterized by higher separation factors and therefore better regeneration of the heat transfer

Heat transfer fluid in this solar thermal plant operates at a punishing 400°C

fluid. The plant is skid-mounted, so that it can also be used as a mobile unit.

GEA Wiegand is a company in the Process Engineering Segment of GEA Group AG. It is active in six fields: evaporation, distillation, filtration, jet pumps, vacuum systems, and scrubbing systems. GEA Wiegand designs and constructs plants mainly in the food, chemical, petrochemical, and environmental sectors.

ACHEMA Hall 4.0 F44
www.gea-wiegand.com

Mixing, emulsifying and more

The EKATO GROUP has new solutions for bulk chemicals, minerals processing, and cosmetics

EKATO RMT, the mixing division of the **EKATO GROUP**, is continuing to develop giant agitators with drive power ratings of 4,000 kW or even more for the next generation of world scale plants. The need for economies of scale is pushing equipment for processing bulk materials – such as chemical and biological reactors, and leaching autoclaves for ores and minerals – to ever-larger sizes, the company points out.

But world-scale reactors are only effective if they are fitted with mixing impellers individually optimized for their specific process requirements. This in turn demands an excellent knowledge of the rules of scale-up, where each new application can be virgin territory. Finally, such critical mixing equipment must be designed to avoid damaging resonance, manufactured to high quality standards, and fitted with condition monitoring systems to promote availability and hence profitability.

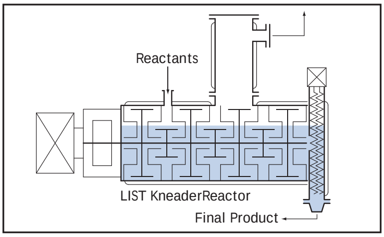
World-scale equipment also implies large gearboxes, which in turn require lubricating oil of guaranteed purity and temperature – especially in hazardous areas, extreme climates, or harsh conditions such as those found in minerals processing. EKATO ESD provides oil supply systems with redundant components for maximum reliability, and a modular design for maximum flexibility.

In the cosmetics industry, meanwhile, EKATO SYSTEMS is setting new standards in the production of health and beauty products, where competitive pressure requires larger and more efficient production equipment. For highly viscous emulsions, EKATO SYSTEMS offers just such equipment in the form of the new UNIMIX SRC 10,000. The proven combination of the PARAVISC agitator with the S-JET/V homogenizer, plus scale-up based on scientific data and practical experience, brings significant productivity increases. In the production of toothpaste, for example, the SRC 10,000 has enabled higher throughput and maximum flexibility in product changeovers, using a 10,000 l batch size.

ACHEMA Hall 5.0 D42
www.ekato.com

Dry Processing: "Simply a more intelligent way"

LIST high-viscosity processing technology allows manufacturers to reduce or even eliminate solvents, with a range of benefits including lower costs and better products



The LIST KneaderReactor offers maximum performance from minimum footprint

As a worldwide technology leader and pioneer in dry or concentrated process technology, **LIST** develops intelligent solutions for the chemical industry. LIST's innovative technology allows processing without solvents, making it more reliable, economical, safe, and environmentally friendly.

LIST's solvent-free technology offers manufacturers of polymers, chemicals, fibers and food products a way to avoid or greatly reduce the need to handle, recover and recycle solvents. This "Dry Processing" makes customers more competitive by dramatically reducing operating costs and plant size, and cutting energy consumption.

Key benefits of Dry Processing include:
- high, continuous, production capacities;
- high degree of processing flexibility when changing grades or process parameters;
- high-efficiency operation, maximizing process yield to process volume;
- environmentally friendly, with low emissions and lower energy use (replaces steam stripping, no solvent to remove);
- economical processing (energy savings, low maintenance, reduced utilities, fewer process steps, smaller footprint);
- high product quality (no overheating of product, no side reactions, no contamination with degraded product, product quality consistent between campaigns); and
- lower cost of ownership.

LIST technology also provides significant health, safety and environmental benefits. Reducing CO_2 emissions, eliminating solvents, and increasing safety through precise thermal management, Dry Processing is simply a more intelligent way to work, the company says.

LIST KneaderReactor technology is successfully applied as a continuous main evaporator or as a continuous bulk polymerizer

Dry Processing has become the choice technology for a portfolio of manufacturing processes across a spectrum of industries. It is LIST's goal to revolutionize other branches of the process industries by helping manufacturers update to Dry Processing.

ACHEMA Hall 5.1 D92
www.list.ch

Where innovation is tradition

SAMSON is a world-leading supplier of control valves to the chemical process industries

SAMSON is a name recognized worldwide as a synonym for high-quality work, entrepreneurial spirit and innovative strength. The company's field of expertise extends from heating and air-conditioning to the largest chemical plants. SAMSON operates wherever there is controlled flow of vapors, gases, or liquids.

Since 1916, the manufacturing plant and head office have been located on the river Main in Frankfurt, Germany. Here product development and manufacturing take place, as well as administration and warehousing. The Frankfurt headquarters and the affiliated companies employ and train over 3,200 people, whose loyalty to the company stems from their sound working environment. The management team, progressive yet traditional, is committed to the SAMSON name and the technical competence and partnership it stands for.

For over 100 years SAMSON has developed and manufactured control equipment for industrial processes. From rugged self-operated regulators to highly specialized control valves for industrial processes, the broad product range includes valves to meet all requirements. The key products are control valves, which SAMSON manufactures in all common sizes, in standard materials and exotic alloys, equipped with actuators tailor-made for the specific demands of the application. Among accessories, SAMSON positioners set the standards with their reliability, accuracy and versatility. They communicate using all common protocols and bus systems, and integrate seamlessly into current process control systems. Most of the control valves and accessories are developed and manufactured at SAMSON's headquarters; in-house manufacturing ensures highest product quality and reliability.

SAMSON's Type 3730–6 positioner with pressure sensors sets standards in cost-effectiveness, flexibility and reliability. Its features include:
- one positioner for throttling and on/off applications;
- integrated EXPERTplus diagnostics;
- TROVIS-VIEW 4 software for configuration and operation free of charge;
- HART communication with free EDDL and FDT/DTM;
- monitoring of the entire operating cycle with EXPERTplus valve diagnostics;
- integrated sensors to monitor supply pressure and signal pressure;
- automated partial stroke test (PST) suitable for safety-instrumented systems up to SIL 3.

Type 3241–7 pneumatic control valve with Type 3730–6 electropneumatic positioner

ACHEMA Hall 11.1 C75
www.samson.de, www.samsongroup.de

Centrifugal separation from a technology leader

GEA Westfalia Separator Group sees its products as key to a better environment

Effective and economical separation of liquids and solids is essential to the well-being of the world's citizens

GEA Westfalia Separator Group is a company within the internationally active GEA Group. With more than 50 sales and service companies all over the world, the group holds pole position in the field of mechanical separation technology. Since 1893 GEA Westfalia Separator Group has been building centrifuges for the separation of liquids and liquid mixtures. This efficient technology brings decisive added value, says the company: better quality of life for humans, more sustainable yield for the Earth – and greater profitability for the firms that take advantage of it.

Today, almost 7 billion people have to be provided with water, energy, food and medicine. At the same time, the demands for sustainable economic management are increasing. It is only the gentle handling of valuable resources that ensures our quality of life without jeopardizing the fundamentals of future generations. Sustainable growth – this is what the mechanical separation technology of GEA Westfalia Separator Group stands for.

For both separators and decanters, the process lines of GEA Westfalia Separator Group combine a high level of separation precision, degree of clarification and throughput with the greatest possible economies of energy, water, production area and waste disposal requirements.

Based on the experience of more than 3,000 applications in process technology and a history of rapidly turning innovations into marketable processes, GEA Westfalia Separator Group provides profitable answers to some of the biggest challenges of our time.

GEA Westfalia separators and decanters are centrifuges that are used to separate solids from liquids or liquid mixtures and to remove solids at the same time. They are used for clarifying suspensions, for separating liquid mixtures with simultaneous solids removal, and for concentrating and dewatering solids.

ACHEMA Hall 4 F44
Anuga FoodTec Hall 4.1 A031–D038
IFAT ENTSORGA Hall A1 419/518
www.westfalia-separator.com

MARCH New Products

BinMaster

Wika Alexander Wiegand

Bronkhorst High-Tech

Stateview

This pressure switch is designed to avoid clogging

To serve industrial processes with "critical" media, this company has expanded its range of electronic pressure switches with the addition of the PSD-31 with flush diaphragm (photo). This device is particularly suited for applications in abrasive, aggressive, adhesive, crystalline and viscous media. Its flush connection eliminates any clogging of the pressure channel with particles and also prevents possible contamination of the process. — *Wika Alexander Wiegang SE & Co. KG, Klingenberg, Germany*

www.wika.de

Another fieldbus interface is now available for these flowmeters

An EtherCAT fieldbus interface is now available for this company's thermal mass flowmeters and controllers for gases (photo) and liquids, as well as its digital pressure controllers. EtherCAT is said to be a highly flexible Ethernet-network protocol that operates at high speed, with high efficiency and offers simple configuration. With its multi-bus concept, the company offers flexibility by equipping its digital instruments with interface boards for DeviceNet, Profi-DP, Modbus or FlowBus. — *Bronkhorst High-Tech B.V., Ruurlo, the Netherlands*

www.bronkhorst.com

A level gage for challenging storage applications

The 3DLevelScanner HE (photo) is designed for use in storage silos containing challenging materials, such as clinker, alumina and flyash. This new model of the scanner has an operating temperature range of up to 250°F, to accommodate higher temperatures that may be present when material that has been heated in the production process is conveyed into storage silos. The device is suitable for applications in the cement, aluminum and power industries where there are multiple challenges, such as dust or high humidity, and very large silos where the material surface in the bin may be uneven and difficult to measure. — *BinMaster, a div. of Garner Industries, Lincoln, Neb.*

www.binmaster.com

Cut, bevel and weld pipe — with a single machine

The Axxair range of pipe cutting, beveling and welding machines has been added to this company's range of products. By simply exchanging motors, these machines can cut pipe, then bevel the ends and weld parts. The unit cuts stainless steel, mild steel and other alloy pipes with thicknesses of between 0.5 and 15 mm and pipe diameters ranging from 5 to 1,000 mm, and bevels pipe with thicknesses between 0.5 and 0.8 mm. — *Weldwide Solutions Ltd., Llanelli, U.K.*

www.weldwidesolutions.com

Hollow-fiber membrane modules for ultrafiltration applications

Introduced to the Spanish market last month, the Targa II hollow-fiber ultrafiltration cartridge is suitable for a wide range of ultrafiltration applications, including industrial water treatment, seawater pretreatment and tertiary wastewater treatment. The element features robust polyethersulfone (PES) membranes that, combined with optimized cartridge and rack design, results in one of the smallest-footprint products available, says the company. Hollow-fiber membranes easily handle clean water for processing as well as fluids with low solids in circulation, dead-end and single-pass operations. — *Koch Membrane Systems Ltd., Aachen, Germany*

www.kochmembrane.com

Detect leaks from heating pipes with this system

Last month, this company launched a new version of its Stateview system for detecting leaks in district energy systems. Stateview System II (photo) boasts a ten-fold increase in wireless reach — to 1,000 m — giving field workers a much-improved environment, says the manufacturer. Stateview is a portable diagnostic tool for district energy pipe networks. It operates analogously to radar, sending electrical signals along pipes, and giving heating stations a tool for early detection of damaged pipes without having to actually dig up the pipes or wait for a pipe to break. — *Stateview, a subsidiary of Mittel Fjärrvärme AB, Umeå, Sweden*

www.mittel.se ■

Gerald Ondrey

For more New Products See page 63

Note: For more information, circle the 3-digit number on p. 70, or use the website designation.

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Selecting Two- and Four-wire Magnetic Flowmeters

To optimize process control and overall plant performance, magnetic flowmeters (mag meters) are the most widely used devices in many industrial flow-measurement applications. Mag meters are used to measure the flow of water and other conductive liquids by applying a magnetic field to the flowing liquid. Following Faraday's law of electromagnetic induction, conductive liquid flowing through the magnetic field induces a voltage signal that can be detected by electrodes on the pipe walls. Fluid flowrate is proportional to voltage: faster-moving fluids generate higher voltage signals. Mag meter technologies produce signals that are linear with flowrate.

Mag meter advantages

Mag meters have several key advantages over alternatives, including exceptionally high accuracy, (within the range of 0.5%). Chemical feed applications require highly accurate and stable flow measurements, making them a good fit for mag meters. Mag meters are volumetric flowmeters, free of moving parts. This means they are much less susceptible to wear-and-tear than contact meters, particularly those with moving parts, such as turbine flowmeters. Also, the lack of moving parts minimizes the loss of accuracy over time that many other meter types can experience.

Mag meters can be used with pipes of almost any size and are ideal for applications where low pressure drop and minimal maintenance are required.

While mag meters can measure a wide range of aqueous solutions and slurries, they are not suitable for low-conductivity solutions, such as distilled water, hydrocarbon-containing solutions and non-aqueous solutions and gases.

Two- versus four-wire mag meters

Mag meters are offered in both two-wire, loop-powered format and four-wire, separately powered configurations. The basic difference is that two-wire mag meters do not require separate wiring to a power source, as they receive power from the 4–20-mA loop power supply. Aside from the wiring, another main difference between the two- and four-wire flowmeters is the strength of the magnetic field. With their greater power input, four-wire mag meters can generate a more powerful magnetic field, which can be an advantage for some applications.

Four-wire mag meters are most commonly used for more standard applications because that type was developed first. Because of that, they are widely supported by thousands of compatible devices, including wireless transducers. They work with many different wire conductors and connectors, even with poor-quality connections. Modern variations of 4–20 mA, such as those using the HART communication protocol, continue to drive support for the four-wire meter as the standard.

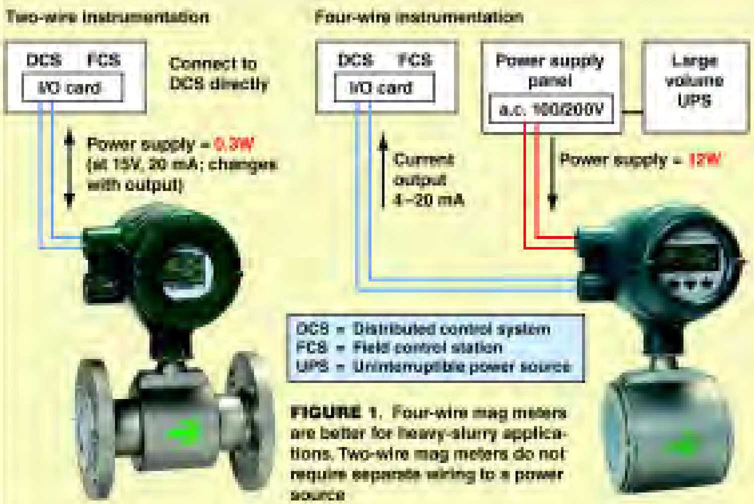


FIGURE 1. Four-wire mag meters are better for heavy-slurry applications. Two-wire mag meters do not require separate wiring to a power source

Selection considerations

Both meter types can provide good value in the applications for which they are intended. Both have advantages and disadvantages, so engineers need to decide which type is better-suited to the application. The following are a number of considerations that are important to the selection of a two-wire or four-wire mag meter.

Slurries or clean fluids. The consistency of the liquid being measured is the most important determining factor when choosing which type of mag meter to use. Four-wire mag meters are better for heavy-slurry applications. Two-wire mag meters are used for clean fluids, but can also be used for light slurries.

Signal noise. Four-wire mag meters typically are more tolerant of process-generated noise in the fluid to be measured than the two-wire type. Two-wire magnetic flowmeters are good for low-noise applications with cleaner fluids.

Cost and size. Four-wire mag meters are slightly less expensive at initial purchase, but two-wire mag meters offer cost savings in installation because they require less wiring overall and do not require an independent power source.

Energy requirements. Four-wire mag meters generally use more power. However, since a two-wire mag meter is powered by the controller's analog input module, it is important not to overload the module. Engineers should check the nameplate on the meter for a Watt- or burden-rating. For example, a 4–20-mA two-wire mag meter on a 24-V d.c. loop supply will draw nearly 0.5 W at full span (24 V x 0.02 A = 0.48 W).

The latest two-wire meters offer exceptional energy efficiency, consuming as little as 1–4% of the power needed for a four-wire unit. This 96% reduction in power consumption also reduces annual CO_2 emissions from 46 kg to 1.2 kg. Lower energy consumption also contributes to a lower total cost of ownership for a two-wire mag meter.

For example, the estimated lifetime energy savings from a two-wire mag meter, could exceed $10,000:

$10/y x 100 m = $1,000/y

Lifetime (10 y) savings = $10,000

Advanced designs. There are certain instances in which advanced two-wire mag meters can be used in applications that traditionally would have called for the use of a four-wire mag meter. A two-wire mag meter is now available that uses a dual-frequency excitation method. The dual-frequency excitation provides the two-wire instrument with the same level of process-generated noise immunity as a four-wire flowmeter under a wide range of fluid conditions, including light slurries.

The new type of two-wire mag meters are also capable of suppressing noise without sacrificing fast response time. This is due to an advanced electromagnetic design that generates a relatively strong magnetic field with only the limited power available from the two wires in a 4–20-mA loop power installation.

Handling corrosive liquids. Magnetic flowmeters can be used to measure corrosive liquids and abrasive slurries. However, it is important to choose a flowmeter fabricated with materials that are compatible with the types of fluids used in the application.

Editor's note: Content for this edition of "Facts at Your Fingertips" was contributed by Sam Hassan, product specialist at Yokogawa Corp. of America (Newnan, Ga.; www.yokogawa.com/us).

Determining Friction Factors in Turbulent Pipe Flow

Several approaches are reviewed for calculating fluid-flow friction factors in fluid mechanics problems using the Colebrook equation

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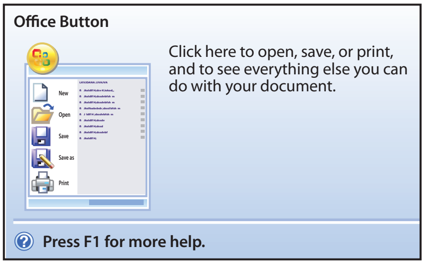

FIGURE 1. Microsoft Excel can carry out iterative calculations as needed in solving the implicit Colebrook equation

Head loss due to friction for fluids traveling through pipes, tubes and ducts is a critical parameter for solving turbulent-flow problems in the chemical process industries. The Colebrook equation is used to assess hydraulic resistance for turbulent flow in both smooth- and rough-walled pipes. The equation contains a dimensionless fluid-flow friction coefficient that must be calculated for the properties of the pipe and the fluid flow.

Determining friction factors for the Colebrook equation requires either calculating iteratively or manipulating the equation to express friction factors explicitly. Iterative calculations can be carried out using a spreadsheet solver, but can require more computational time. Explicit expressions offer direct computation, but have a range of simplicity and corresponding error.

The Lambert W function may be a better method to express friction factors explicitly because it allows users to avoid iterative calculation and also reduce relative error. This article outlines methods for determining friction factors, and discusses how to use the Lambert W function. The Lambert W function is evaluated using real data in Part 2 of the feature (p. 40).

Colebrook equation

Pipe-flow problems are challenging because they require determination of the fluid-flow friction factor (λ), a dimensionless term whose expression is a non-factorable polynomial. The friction factor is a complicated function of relative surface roughness and Reynolds number (*Re*), where, specifically, hydraulic resistance depends on flowrate. The situation is similar to that observed with electrical resistance when a diode is in circuit.

The hydraulics literature contains three forms of the Colebrook equation for which the friction factor is implicit, meaning that the term it has to be approximately solved using an iterative procedure because the term exists on both sides of the equation. Engineers have also developed a number of approximation formulas that express the friction factor explicitly, meaning that it is calculated directly rather than through an iterative process.

The equation proposed by Colebrook in 1939 [*1*] describes a monotonic change in the friction factor as pipe surfaces transition from fully smooth to fully rough.

$$\frac{1}{\sqrt{\lambda}} = -2 \cdot \log_{10}\left(\frac{2.51}{\mathrm{Re} \cdot \sqrt{\lambda}} + \frac{\varepsilon}{3.71 \cdot D}\right) \quad (1)$$

At the time it was developed, the implicit form of the Colebrook equation was too complex to be of great practical use. It may be difficult for many to recall the time, as recently as the 1970s, with no personal computers or even calculators that could do much more than add or subtract.

Many researchers, such as Coelho and Pinho [*2*], have adopted a modification of the implicit Colebrook equation, using 2.825 as the constant instead of 2.51. Alternatively, some engineers use the Fanning factor, which is different from the more commonly used Darcy friction factor. The Darcy friction factor is four times greater than the Fanning friction factor, but their physical meanings are equivalent.

Calculation approaches

In general, the following five approaches are available to solve the Colebrook equation:

- Graphical solutions using Moody or Rouse diagrams (useful only as an orientation)
- Iterative solutions using spreadsheet solvers (can be highly accurate to Colebrook standard, but require more computational resources)
- Using explicit Colebrook-equation approximations (less computation, but can introduce error)
- Lambert W function (avoids iterative calculations and allows reduction of relative error)
- Trial-and-error method (obsolete)

Graphical solutions

Graphs based on the Colebrook equation represent the simplest, but most approximate approach to avoiding trial-and-error-based iterative solutions. In 1943, Rouse [*3*] developed a chart based upon the Colebrook equa-

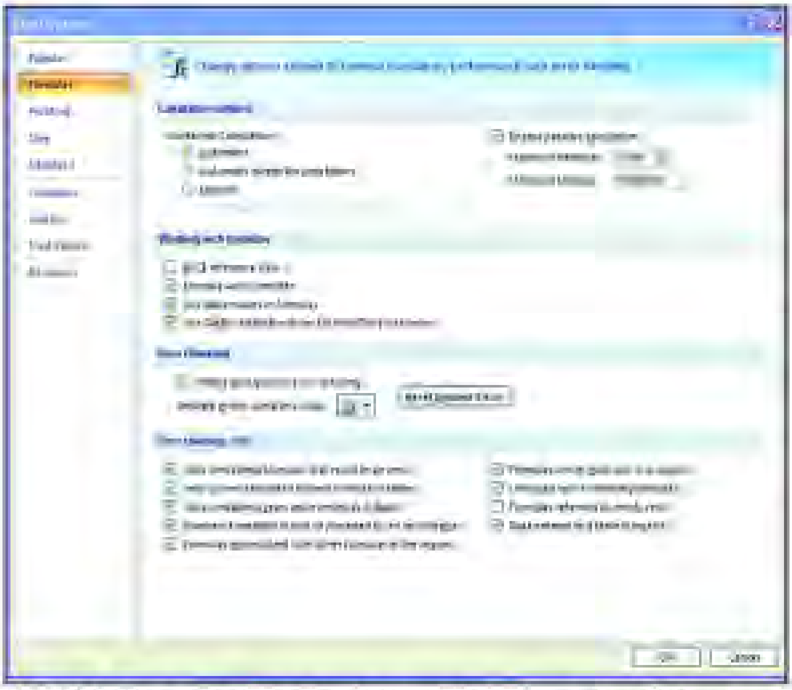

FIGURE 2. The number of iterations to run and the maximum change between iterations must be set when calculating in Microsoft Excel 2007

tion that allowed it to be used more practically. In the Rouse diagram, Reynolds number is related to friction factor and the friction factor (λ) is implicit for both coordinates, (that is, $Re \cdot \sqrt{\lambda} = f\left(1/\sqrt{\lambda}\right)$). In order to simplify this chart for more ordinary engineering use, Moody [4] adopted more convenient coordinates the following year, plotting *Re* versus *f*(λ). To be precise, as the primary axis, Rouse used $Re \cdot \sqrt{\lambda} = f\left(1/\sqrt{\lambda}\right)$ and $Re = f(\lambda)$ as the secondary axis, while Moody used only $Re = f(\lambda)$.

Iterative spreadsheet solutions

Today, implicit equations such as the Colebrook can be solved easily and accurately using the Newton-Raphson iterative procedure and common software tools like Microsoft Excel 2007 (Figures 1 and 2). The maximum number of iterations in Excel 2007 is 32,767. To solve for the unknown friction factor λ, one must start by estimating the value of the friction factor on the right side of the equation, then solve for the new friction factor on the left. The new value would then be entered back on the right side, and the process continued until there is a balance on both sides of the equation within an arbitrary difference. This difference must be small, yet accommodate all values of relative roughness (ε/*D*) and values of Reynolds number without causing endless computations.

Note that the Colebrook equation consists of two parts: the first part is equal to zero in first iteration (meaning that $2.51 / (Re \cdot \sqrt{\lambda}) = 0$), but the second part has a value different than zero ($\varepsilon / (D \cdot 3.71) \neq 0$), so estimating the value in the first iteration is unnecessary. The initial value in the first iteration is $\varepsilon / (D \cdot 3.71)$.

In some cases, seemingly effective solutions are too simple to generate the required accuracy, and Excel is an ideal tool to solve these kinds of problems. Excel allows accuracies to within at least 0.01. The maximum accuracy can be set to 0.0000001.

To solve the implicit Colebrook equation, click the Excel "Office button" in the upper left of the screen (Figure 1). Then click "Excel options," and "Formulas." In the Formulas array, check the box for "Enable iterative calculation" and enter the maximum number of iterations desired. The maximum change allowed between two successive iterations also must be set in the program.

NOMENCLATURE

- *Re* Reynolds number (dimensionless)
- λ Darcy friction factor (dimensionless)
- ε Absolute roughness of inner surface of pipe, ft; m in SI units
- *D* Inner pipe diameter, ft; m in SI units
- *W* Lambert function X argument of W function
- *x* Argument of Taylor series or argument of Lambert W function
- *n* Integers

Explicit approximations

Many explicit approximations of the Colebrook equation are available (Table 1), including those from Moody [5], Wood [6], Eck [7], Swamee and Jain [8], Churchill [9–10], Jain [11], Chen [12], Round [13], Barr [14], Zigrang and Sylvester [15], Haaland [16], Serghides [17], Manadilli [18], Romeo and others. [19], Sonnad and Goudar [20], Buzzelli [21], Vatankhah and Kouchakzadeh [22], Avci and Karagoz [23], Papaevangelou et al. [24]. These approximations vary in their degree of accuracy, depending upon the complexity of their functional forms. The more complex ones generally estimate friction factors with higher accuracy (Table 1). Only approximations proposed by Moody [5], Wood [6], Eck [7] and Round [13] have maximum errors greater than 5%. Accuracy of approximations to the Colebrook equation is examined by Zigrang and Sylvester [15], Gregory and Fogarasi [26] and Yildirim [27].

Using the Lambert W function

The approximation proposed by the author is developed using the Lambert W function. Functions involving exponents, logarithms and square roots are indispensible tools in solving broad classes of mathematical problems. With just four basic operations of arithmetic, any linear equation can be solved. Quadratic equations can be solved as well if square roots are added. For some classes of problems, trigonometric functions are useful. These functions can be classified as elementary. But for the solution of implicit equations such as the Colebrook,

TABLE 1. EXPLICIT APPROXIMATIONS TO THE COLEBROOK RELATION		
Relation	**Auxiliary terms**	**Name-year**
$\lambda \approx 0.0055 \cdot \left(1 + \left(2 \cdot 10^4 \cdot \frac{\varepsilon}{D} + \frac{10^6}{\mathrm{Re}}\right)^{\frac{1}{3}}\right)$	-	Moody-1947
$\lambda \approx 0.094 \cdot \left(\frac{\varepsilon}{D}\right)^{0.225} + 0.53 \cdot \left(\frac{\varepsilon}{D}\right) + 88 \cdot \left(\frac{\varepsilon}{D}\right)^{0.44} \cdot \mathrm{Re}^{-\Psi}$	$\Psi = 1.62 \cdot \left(\frac{\varepsilon}{D}\right)^{0.134}$	Wood-1966
$\frac{1}{\sqrt{\lambda}} \approx -2 \cdot \log\left(\frac{\varepsilon}{3.715 \cdot D} + \frac{15}{\mathrm{Re}}\right)$	-	Eck-1973
$\frac{1}{\sqrt{\lambda}} \approx -2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot D} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)$	-	Swamee and Jain-1976
$\frac{1}{\sqrt{\lambda}} = -2 \cdot \log\left(\frac{\varepsilon}{D \cdot 3.71} + \left(\frac{7}{\mathrm{Re}}\right)^{0.9}\right)$	-	Churchill-1973
$\frac{1}{\sqrt{\lambda}} \approx -2 \cdot \log\left(\frac{\varepsilon}{3.715 \cdot D} + \left(\frac{6.943}{\mathrm{Re}}\right)^{0.9}\right)$	-	Jain-1976
$\lambda \approx 8 \cdot \left[\left(\frac{8}{\mathrm{Re}}\right)^{12} + \frac{1}{(\Theta_1 + \Theta_2)^{1.5}}\right]^{\frac{1}{12}}$	$\Theta_1 = \left[2.457 \cdot \ln\left[\left(\frac{7}{\mathrm{Re}}\right)^{0.9} + 0.27 \cdot \frac{\varepsilon}{D}\right]\right]^{16}$ $\Theta_2 = \left(\frac{37530}{\mathrm{Re}}\right)^{16}$	Churchill*-1977
$\frac{1}{\sqrt{\lambda}} \approx -2.0 \cdot \log\left[\frac{\varepsilon}{3.7065 \cdot D} - \frac{5.0452}{\mathrm{Re}} \cdot \log\left(\frac{1}{2.8257}\left(\frac{\varepsilon}{D}\right)^{1.1098} + \frac{5.8506}{\mathrm{Re}^{0.8981}}\right)\right]$		Chen-1979
$\frac{1}{\sqrt{\lambda}} \approx 1.8 \cdot \log\left[\frac{\mathrm{Re}}{0.135 \cdot \mathrm{Re} \cdot \left(\frac{\varepsilon}{D}\right) + 6.5}\right]$	-	Round-1980
$\frac{1}{\sqrt{\lambda}} \approx -2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot D} + \frac{4.518 \cdot \log\left(\frac{\mathrm{Re}}{7}\right)}{\mathrm{Re}\left(1 + \frac{\mathrm{Re}^{0.52}}{29} \cdot \left(\frac{\varepsilon}{D}\right)^{0.7}\right)}\right)$	-	Barr-1981
$\frac{1}{\sqrt{\lambda}} \approx -2 \cdot \log\left[\frac{\varepsilon}{3.7 \cdot D} - \frac{5.02}{\mathrm{Re}} \cdot \log\left(\frac{\varepsilon}{3.7 \cdot D} - \frac{5.02}{\mathrm{Re}} \cdot \log\left(\frac{\varepsilon}{3.7 \cdot D} + \frac{13}{\mathrm{Re}}\right)\right)\right]$ or $\frac{1}{\sqrt{\lambda}} \approx -2 \cdot \log\left[\frac{\varepsilon}{3.7 \cdot D} - \frac{5.02}{\mathrm{Re}} \cdot \log\left(\frac{\varepsilon}{3.7 \cdot D} + \frac{13}{\mathrm{Re}}\right)\right]$	-	Zigrang and Sylvester-1982
$\frac{1}{\sqrt{\lambda}} \approx -1.8 \cdot \log\left[\left(\frac{\varepsilon}{3.7 \cdot D}\right)^{1.11} + \frac{6.9}{\mathrm{Re}}\right]$	-	Haaland-1983

Continues on next page

TABLE 1. EXPLICIT APPROXIMATIONS TO THE COLEBROOK RELATION (Continued)

Relation	Auxiliary terms	Name, year
$\lambda \approx \left[\Psi_1 - \frac{(\Psi_2-\Psi_1)^2}{\Psi_3-2\Psi_2+\Psi_1}\right]^{-2}$ or $\lambda \approx \left[4.781 - \frac{(\Psi_1-4.781)^2}{\Psi_2-2\Psi_1+4.781}\right]^{-2}$	$\Psi_1 = -2\cdot\log\left(\frac{\varepsilon}{3.7\cdot D}+\frac{12}{\mathrm{Re}}\right)$ $\Psi_2 = -2\cdot\log\left(\frac{\varepsilon}{3.7\cdot D}+\frac{2.51\cdot\Psi_1}{\mathrm{Re}}\right)$ $\Psi_3 = -2\cdot\log\left(\frac{\varepsilon}{3.7\cdot D}+\frac{2.51\cdot\Psi_2}{\mathrm{Re}}\right)$	**Serghides, 1984**
$\frac{1}{\sqrt{\lambda}} \approx -2\cdot\log\left(\frac{\varepsilon}{3.7\cdot D}+\frac{95}{\mathrm{Re}^{0.983}}-\frac{96.82}{\mathrm{Re}}\right)$	-	**Manadilli, 1997**
$\frac{1}{\sqrt{\lambda}} \approx -2\cdot\log\left\{\frac{\varepsilon}{3.7065\cdot D}-\frac{5.0272}{\mathrm{Re}}\cdot\log\left[\frac{\varepsilon}{3.827\cdot D}-\frac{4.567}{\mathrm{Re}}\log\left(\left(\frac{\varepsilon}{7.7918\cdot D}\right)^{0.9924}+\left(\frac{5.3326}{208.815+\mathrm{Re}}\right)^{0.9345}\right)\right]\right\}$		**Romeo, Royo and Monzón, 2002**
$\frac{1}{\sqrt{\lambda}} \approx 0.8686\cdot\ln\left[\frac{0.4587\cdot\mathrm{Re}}{S^{S/(S+1)}}\right]$	$S = 0.124\cdot\mathrm{Re}\cdot\frac{\varepsilon}{D}+\ln(0.4587\cdot\mathrm{Re})$	**Sonnad and Goudar, 2006**
$\frac{1}{\sqrt{\lambda}} \approx 0.8686\cdot\ln\left[\frac{0.4587\cdot\mathrm{Re}}{(S-0.31)^{S/(S+0.9633)}}\right]$	$S = 0.124\cdot\mathrm{Re}\cdot\frac{\varepsilon}{D}+\ln(0.4587\cdot\mathrm{Re})$	**Vatankhah and Kouchakzadeh, 2008**
$\frac{1}{\sqrt{\lambda}} \approx \alpha - \left[\frac{\alpha+2\cdot\log\left(\frac{\beta}{\mathrm{Re}}\right)}{1+\frac{2.18}{\beta}}\right]$	$\alpha = \frac{(0.774\cdot\ln(\mathrm{Re}))-1.41}{\left(1+1.32\cdot\sqrt{\frac{\varepsilon}{D}}\right)}$ $\beta = \frac{\varepsilon}{3.7\cdot D}\cdot\mathrm{Re}+2.51\cdot\alpha$	**Buzzelli, 2008**
$\lambda \approx \frac{6.4}{\left(\ln(\mathrm{Re})-\ln\left(1+0.01\cdot\mathrm{Re}\cdot\frac{\varepsilon}{D}\cdot\left(1+10\cdot\sqrt{\frac{\varepsilon}{D}}\right)\right)\right)^{2.4}}$		**Avci and Karagoz, 2009**
$\lambda \approx \frac{0.2479-0.0000947\cdot(7-\log\ \mathrm{Re})^4}{\left(\log\left(\frac{\varepsilon}{3.615\cdot D}+\frac{7.366}{\mathrm{Re}^{0.9142}}\right)\right)^2}$	-	**Papaevangelou, Evangelides and Tzimopoulos, 2010**
$\frac{1}{\sqrt{\lambda}} \approx -2\cdot\log\left(10^{-0.4343\cdot S}+\frac{\varepsilon}{3.71\cdot D}\right)$ or $\frac{1}{\sqrt{\lambda}} \approx -2\cdot\log\left(\frac{2.108\cdot S}{\mathrm{Re}}+\frac{\varepsilon}{3.71\cdot D}\right)$	$S = \ln\frac{\mathrm{Re}}{1.623\cdot\ln\left(\frac{1.1\cdot\mathrm{Re}}{\ln(1+1.1\cdot\mathrm{Re})}\right)}$ **Using above *S*, new *S* (noted as S_1) can be calculated to reduce error:** $S_1 = 1.4586887\cdot S-0.4586887\cdot\ln\left(\frac{\mathrm{Re}\cdot 0.917365}{\ln(1+\mathrm{Re}\cdot 0.917365)}\right)$ $S_1 = \ln\left(0.488\cdot\mathrm{Re}\cdot\left[\ln\left(\frac{\mathrm{Re}}{S}\right)\right]^{-1}\right)$ **Or *S* can be calculated as:** $S = \ln(1+0.458\cdot\mathrm{Re})\cdot\left(1-\frac{\ln(1+\ln(1+0.458\cdot\mathrm{Re}))}{2+\ln(1+0.458\cdot\mathrm{Re})}\right)$	

*Churchill relation from 1977 also covers laminar regime the best function is Lambert W [28–29]. The Lambert W function (Equation 2; Figure 3) and the Colebrook equations are transcendental.

$$W(x)\cdot e^{W(x)} = x \qquad (2)$$

The exponential function can be defined, in a variety of equivalent ways, as an infinite series. In particular, it may be defined by a power series in the form of a Taylor series expansion (Equation 3):

$$e^x \approx 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \ldots + \frac{x^n}{n!} \qquad (3)$$

The Taylor series is a mathematical representation of a function as an infinite sum of terms calculated from the values of its derivatives at a single point. Using a Taylor series, trigonometric functions can be written as Equations (4) and (5):

$$\sin x \approx x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \cdots + \frac{(-1)^{n-1}\cdot x^{2\cdot n-1}}{(2\cdot n+1)!} \qquad (4)$$

$$\cos x \approx 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} \cdots + \frac{(-1)^{n}\cdot x^{2\cdot n}}{(2\cdot n)!} \qquad (5)$$

Similarly, the principal branch of the Lambert W function can be noted as in Equation (6):

$$W_0(x) \approx x - x^2 + \frac{3}{2}\cdot x^3 - \frac{8}{3}\cdot x^4 + \frac{125}{24}\cdot x^5 - \cdots + \frac{(-n)^{n-1}\cdot x^n}{n!} \qquad (6)$$

A logical question that arises is why the Lambert W function is not an elementary function, while trigonometric, logarithmic, exponential and others are. Whether Lambert W ultimately attains such canonical status will depend on whether the wider mathematics community finds it sufficiently useful. Note that the Taylor series appears on most pocket calculators, so it is readily usable.

For real-number values of the argument x, the W function has two

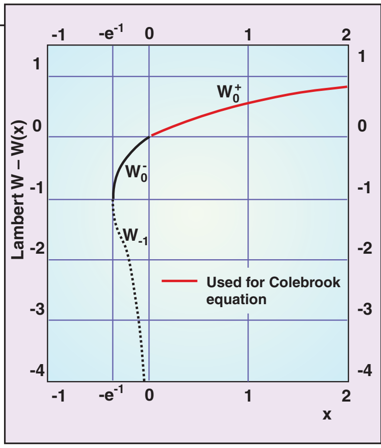

FIGURE 3. The Lambert W function can be defined as an infinite series

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branches: W_{-1} and W_0, where the latter is the principal branch. The evolution of the W function began with ideas proposed by J.H. Lambert in 1758 and the function was refined by L. Euler over the subsequent two decades. Only part of the principal branch of the Lambert W function will be used for solving the Colebrook equation. The equation can be written in explicit form in an exact mathematical way without any approximation involved (Equation 7):

$$\frac{1}{\sqrt{\lambda}} = -2\cdot\log\left(10^{\frac{-1}{\ln(10)}W\left[\frac{Re\cdot\ln(10)}{5.02}\right]} + \frac{\varepsilon}{3.71\cdot D}\right) = -2\cdot\log\left(\frac{5.02\cdot W\left[\frac{Re\cdot\ln(10)}{5.02}\right]}{Re\cdot\ln(10)} + \frac{\varepsilon}{3.71\cdot D}\right) \tag{7}$$

Where $x = Re\cdot\ln(10)/5.02$. Also, procedures to arrive at the solution of the reformulated Lambert W function could find application in commercial software packages.

The Lambert W function is implemented in many mathematical systems, such as Mathematica by Wolfram Research, under the name ProductLog, or Matlab by MathWorks, under the name Lambert [*30*].

Regarding the name of the Colebrook equation, it is sometimes alternately known as the Colebrook-White equation, or the CW equation [*31*].Cedric White was not actually a coauthor of the paper where the equation was presented, but Cyril Frank Colebrook made a special point of acknowledging the important contribution of White for the development of the equation. So the letter W has additional symbolic value in the reformulated Colebrook equation.

Summary of uses

In solving the Colebrook equation approximately, the trial-and-error method is obsolete, and the graphical solution approach is useful only as an orientation. A spreadsheet solver, such as Excel, can generate accurate iterative solutions to the implicit Colebrook equation. The numerous explicit approximations available are also very accurate for solution to the equation. Finally, the new approach using the Lambert W function can be useful [*32–34*]. ■

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Simplifying the Use of Pipe-flow Friction-Factors

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The Lambert W function can help determine accurate values for fluid friction factors and eliminate the need for iterative approaches

The Nikuradse-Prandtl-von Karman (NPK) equation is the most widely used expression to determine friction factors for fluid flow in smooth pipes [*1–3*]. It implicitly relates the friction factor (expressed here as *f*; sometimes called λ) to the Reynolds number, *Re*. It is shown in Equation (1).

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(Re\sqrt{f}\right) - 0.8 \qquad (1)$$

Because the friction factor appears on both sides of the equation, an iterative approach is required to arrive at accurate values for *f*. To simplify the practical use of the NPK equation while providing highly accurate *f* values and eliminating the need for iterative estimations of *f*, several empirical approximations have been proposed [*4*] (see Part 1 of this feature, p. 34).

The authors employed the Lambert W function to derive an explicit representation of the NPK equation for turbulent flow in smooth pipes and used the expression to determine the accuracy of numerous empirical approximations of the NPK equation [*4, 5*]. More recently, other studies have used newer experimental data sets to derive an alternate relationship between *f* and *Re* [*6, 7*], and it is shown here:

$$\frac{1}{\sqrt{f}} = -1.930\log_{10}\left(Re\sqrt{f}\right) - 0.53 \qquad (2)$$

While functionally identical to the NPK equation, Equation (2) has different constants. Using two sources of experimental data, a comparison was made between the new expression and the widely used NPK equation and is presented here. Specifically, explicit representations of Equations (1) and (2) were derived using the Lambert W function that allowed estimation of *f* to machine precision. Subsequently, experimental *f* versus *Re* data were compared with estimates from Equations (1) and (2) to determine their respective deviations from observed values.

Equation (2) was shown to effectively describe experimental data in the range of $31 \times 10^3 < Re < 35 \times 10^6$. In the first data set for which Equation (2) was derived, Equation (2) was more accurate than the NPK equation with average and maximum errors of 0.51% and 1.78%, respectively, compared with 1.94% and 4.06%, respectively, for the NPK equation. For the second data set, both equations were very similar, with average errors of 2.06% and 2.27% and maximum errors of 4.84% and 4.88%, respectively. When *f* estimates were compared over $4 \times 10^3 < Re < 10^8$, the range typically encountered in practice, the average and maximum differences were 1.70% and 3.25%, respectively. Given the inherent experimental error (1.1–4%) and the relatively minor differences in *f*, either equation may be used for turbulent-flow friction-factor estimation in smooth pipes. The single explicit representation with two constants presented in this study should make it easy to incorporate *f* calculations using either expression into existing piping-system design software.

Deriving explicit equations

Equations (1) and (2) can be rewritten as the following:

$$\frac{1}{\sqrt{f}} = C_1 \ln\left(Re\sqrt{f}\right) - C \qquad (3)$$

Where $C_1 = -2.0$ and -1.930 and $C_2 = 0.8$ and 0.537 for Equations (1) and (2), respectively. Equation (3) can be rewritten as the following:

$$\frac{1}{\sqrt{f}} + C_1 \ln\left(\frac{1}{\sqrt{f}}\right) = C_1 \ln(Re) - C_2 \qquad (4)$$

Substituting $\phi = 1/C_1\sqrt{f}$ and simplifying results yields the following:

$$\phi + \ln(\phi) = \ln\left(\frac{Re}{C_1}\right) - \frac{C_2}{C_1} \qquad (5)$$

This may be expressed analogous to the Lambert W function, which is defined as follows [*8*]:

$$W(x) + \ln\{W(x)\} = \ln(x) \qquad (6)$$

From Equations (5) and (6), φ may be written as the following:

$$\phi = W\left\{\frac{Re}{C_1}\exp\left(-\frac{C_2}{C_1}\right)\right\} \qquad (7)$$

Substituting for $\phi = 1/C_1\sqrt{f}$ in Equation (7) results in the desired explicit expression for the friction factor.

$$\frac{1}{\sqrt{f}} = C_1 W\left\{\frac{Re}{C_1}\exp\left(-\frac{C_2}{C_1}\right)\right\} \qquad (8)$$

Equation (8) explicitly relates *f* and *Re* using the Lambert W function, and is a mathematically exact representation for Equations (1) and (2). Multiple techniques to calculate *W* exist, and the Matlab (Mathworks, Natick, Mass.; www.mathworks.com) implementation — which was shown to be accurate to machine precision [*5*] was used to determine *f* from Equation (8). Percentage error between experimental and calculated *f* values was determined as the following:

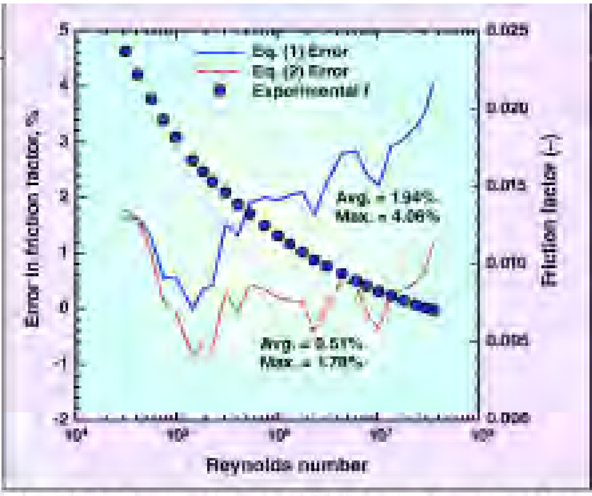

FIGURE 1. Equation (2) was a slightly better descriptor of experimental data for compressed air flow

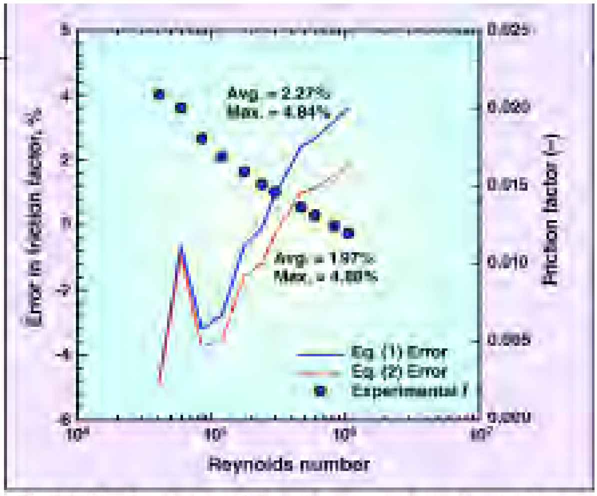

FIGURE 2. Error values for both equations were similar for data from room-temperature gases

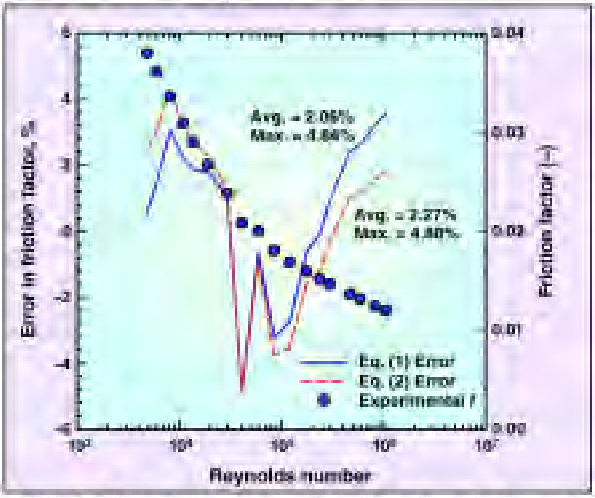

FIGURE 3. Equation (2) has applicability outside the Reynolds number range over which it was initially derived

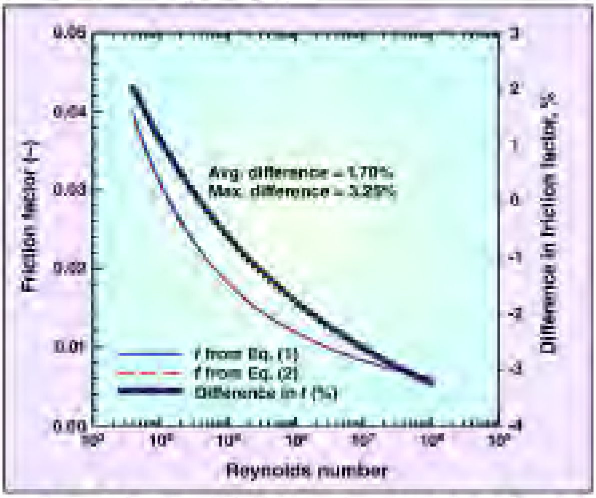

FIGURE 4. Equations (1) and (2) are comparable over the entire range of Reynolds number values typically observed

$$Error = \left(\frac{f_{exp} - f_{cal}}{f_{exp}}\right)100 \qquad (9)$$

where f_{exp} is the experimentally observed f value and f_{cal} is the calculated value from Equation (8), using C_1 and C_2 values for Equation (1) or (2).

Data sets

Comparison using compressed air. A total of 28 f versus Re data points in the $31 \times 10^3 < Re < 35 \times 10^6$ range were obtained for compressed air [6], and this data set was used to derive Equation (2). Experimental f data, along with errors for Equations (1) and (2) (determined using Equation 9) are shown in Figure 1. The average (absolute) errors were 1.94% and 0.51%, while the maximum errors were 4.06% and 1.78%, respectively, for Equations 1 and 2. Thus Equation (2) was a slightly better descriptor of experimental data (the experimental data in Figure 1 were associated with 1.1% error) [6].

Comparison using room temperature gases and liquid helium. In this study, a total of 59 data points were obtained over the $11.21 < Re < 1.0 \times 10^6$ range and the data were characterized by experimental errors of 2–4% [6, 9]. In the initial comparison, 11 data points from the range $40.85 \times 10^3 < Re < 1.05 \times 10^6$ were chosen since they were in the $31 \times 10^3 < Re < 35 \times 10^6$ range for which Equation (2) was derived. Experimental f versus Re data along with error profiles from Equations (1) and (2) is shown in Figure 2. Unlike errors observed in Figure 1, errors in Equations (1) and (2) were similar, with average (absolute) values of 2.27% and 1.97%, and maximum values of 4.84% and 4.88%, respectively.

Another comparison was made with data in the $3.98 \times 10^3 < Re < 1.05 \times 10^6$ range (n = 19). Clearly, the first eight data points were outside the range over which Equation (2) was derived, but this comparison provides information on the applicability of Equation (2) to a wider range of turbulent flow. Experimental data, along with error profiles from Equations (1) and (2), are shown in Figure 3. While the maximum errors were identical to those in Figure 2, the average (absolute) error for Equation (2) in Figure 3 was slightly higher than in Figure 2 (2.27% versus 1.97%) and this was primarily because Equation (2) underestimated f values at lower Re numbers (Figure 3). However, given the inherent error in experimental data (2–4%) and the relatively low and similar average and maximum errors for Equations (1) and (2) in Figure 3, it is clear that Equation (2) has applicability outside the Re range over which it was initially derived.

Comparison of Equations (1) and (2) over $4 \times 10^3 < Re < 10^8$. A comparison of f estimates from Equations (1) and (2) was made over the entire range of turbulent flow typically encountered in practice. Friction factor estimates from Equations (1) and (2), along with the percentage difference in estimates, are shown in Figure 4 for 1,000 logarithmically spaced *Re* values in the $4 \times 10^3 < Re < 10^8$ range. For $4 \times 10^3 < Re < 38.35 \times 10^3$, *f* estimates from Equation (1) were higher than those from Equation (2), and the error difference between Equations (1) and (2) decreased monotonically with *Re* from 2.02% at $Re = 4 \times 10^3$ to 5.9×10^{-4}% at $Re = 38.35 \times 10^3$. For $Re > 38.35 \times 10^3$, *f* estimates from Equation (1) were lower and the error difference also increased monotonically with increasing *Re* values from -6.62×10^{-3} % at $Re = 38.35 \times 10^3$ to 3.25 % at $Re = 10^8$. Overall, the average absolute difference was 1.70%, while the maximum difference was 3.25% (Figure 4). Given that experimental data in very specialized and controlled experiments have errors in the 1.1–4% range [*6, 9*], Figure 4 suggests that both Equations (1) and (2) are comparable over the entire range of *Re* values typically encountered in practice. Their explicit representation as Equation (8) eliminates the need for iterative calculations and should simplify their use in practical applications. ■

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Feature Report

Distillation Optimization By Vapor Recompression

Vapor recompression offers an energy-saving alternative to conventional distillation design

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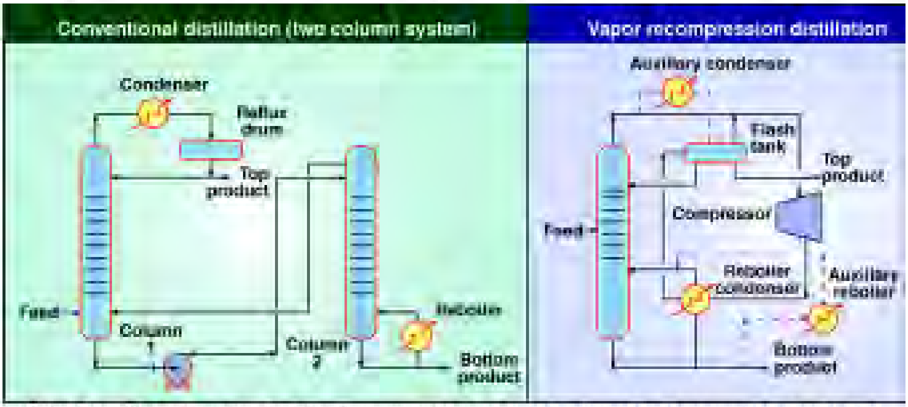

FIGURE 1. This schematic depicts a conventional (left) and a vapor-recompression (right) type of distillation column for a typical C_3-splitter column

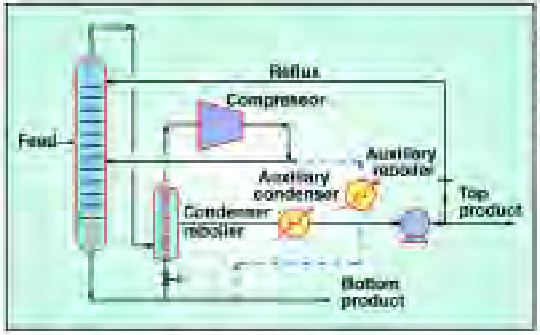

FIGURE 2. An alternate configuration for vapor recompression distillation consists of compressing the reboiler outlet vapors instead of column overhead vapors

Distillation is one of the most extensively used operations in the chemical process industries (CPI). It is a highly energy-intensive unit operation, and continuously rising energy costs make it imperative to look for ways to reduce energy requirements. Some energy-saving configurations can increase capital investment costs, so the benefits need to be weighed carefully. Various techniques, such as heat integration, heat pumps, thermal couplings and others have been employed to achieve energy reductions [2–4]. Vapor-recompression-assisted distillation is one such technique to reduce energy consumption by utilizing the energy from the column overhead stream, with added external mechanical energy, to boil the bottom stream.

This article illustrates the technique through an example of a typical C_3-splitter (propane-propylene splitter) design wherein significant energy savings and operational benefits are achieved by using vapor recompression distillation. With the availability of reliable and proven compressors to handle large capacities for industrial use, this concept is gaining attention and merits consideration for new distillation installations.

The basics

Conventional distillation columns have a separate reboiler and a separate condenser. A vapor-recompression-assisted column has a combined "condenser-reboiler". The basic feature of a vapor-recompression distillation system is utilization of the heat content of the column's overhead vapor to supply heat required in the reboiler. The temperature driving force required to force heat to flow from cooler overhead vapors to hotter bottoms product is provided by compressing the overhead vapor. In such a system, column overhead vapor is first sent to a compressor to raise its pressure and temperature. Heat content of this compressed overhead-vapor stream is then utilized for providing vaporization duty of the reboiler. While giving heat to the bottoms reboiler, the overhead vapor is condensed, and part of it is returned to the column as reflux. Figure 1 shows a schematic arrangement of both conventional and vapor-recompression types of distillation for a typical C_3-splitter column.

As shown in Figure 1, a conventional C_3-splitter column is split into two separate columns due to practical con-

TABLE 1. FEED, PRODUCT AND UTILITY CONDITIONS	
Feed Conditions	
Components	**Mass Fraction**
Propane	0.25
Propylene	0.75
Temperature	40°C
Pressure	25 kg/cm^2 abs
Feed flowrate	50,000 kg/h
Product Specifications	
Overall propylene recovery in overhead product	95 wt.%
Propylene product purity	99.7 wt.%
Available Utilities	
Circulating cooling water	32°C supply and 38°C return
Low pressure steam	Saturated at 3.5 kg/cm^2 gage

TABLE 2. COLUMN SIMULATION RESULTS			
Parameter	**Units**	**Conventional**	**Vapor recompression**
Underwood minimum reflux ratio		10.5	9.0
Operating reflux ratio		16.4	14.3
Number of trays (theoretical)		180	160
Feed tray location (theoretical)		142	127
Reboiler duty	mm kcal/h	44.72	42.97
Condenser duty	mm kcal/h	44.54	6.64 (auxiliary)
Column diameter	mm	6,250	5,800
Maximum jet flooding	%	76.3	76.4
Overhead product rate	kg/h	35,733	35,733
Propylene purity in overhead product	wt.%	99.7	99.7
Reflux pump capacity	m^3/h	1,230.5	975
Intermediate column transfer pump	m^3/h	1,400	not applicable
Operating pressure, top/bottom	kg/cm^2 abs	18.033/18.92	13.033/13.94
Column temperature, top/bottom	°C	42.5/51.5	28.5/38
Compressor power	kW	not applicable	7,045

struction limitations on the height of a single column. Vapor recompression distillation for the same application, however, has only one column with a common reboiler-condenser. A flash tank is added to the flowsheet to avoid the return of flashing reflux back to the column. An alternate configuration for vapor recompression distillation consists of compressing the reboiler outlet vapors instead of column overhead vapors. As shown in Figure 2, this configuration includes lowering the pressure on reboiler liquid so that it boils at a lower temperature, and then compressing the bottoms vapor back to the column pressure. In either case, an auxiliary condenser or an auxiliary reboiler may be required if the column reboiling and condensing heat duties do not match exactly.

For many conventional distillation systems, the column operating pressures are dictated by limitations of either heating- or cooling-media temperatures. In these cases, it is not possible to operate the column at lower pressures to take full advantage of the relative volatility factor. This imposes a constraint on optimization and thus on energy requirements. On the other hand, vapor-recompression-assisted distillation columns can be optimized for lower-pressure operation. The vapor recompression concept is generally applied to close-boiling super fractionator systems due to small temperature differences between condensing and reboiling temperatures [*1*]. If the temperature difference is large, it may result in an uneconomical amount of external work to be added — keep in mind that electricity costs are typically much higher than the costs of other utilities, such as steam or cooling water. Thus, the typical application area for this concept is mainly in the separation of close-boiling mixtures.

There are a number of additional advantages associated with vapor recompression systems. First, a large amount of heat can be moved between the condenser and reboiler with a relatively small work input. This results in overall energy savings. Operating pressures of a vapor-recompression-assisted column can be set where desired to achieve the maximum separation, and are not governed by the cooling- and heating-media utilities available. For close-boiling-point systems the result is significant since relative volatility is improved at lower pressures and separation becomes easier, thus reducing the column height and/or reflux requirements.

C_3-splitter design case study

Using the basic concepts outlined above, a process optimization case study is presented to demonstrate energy savings achieved by employing a vapor recompression scheme for a C_3-splitter column. To illustrate the benefits, energy requirements are compared with a conventional system.

The C_3-splitter column is used for separation of propane and propylene to obtain polymer-grade propylene. This is a commonly encountered industrial separation process. Conventional distillation consists of a single column (typically split into two columns due to height limitations, and connected with a pump for internal, liquid traf-

TABLE 3. OPERATING COST BASIS	
On stream operation	8,000 h/yr
Circulating cooling-water cost	\$0.05 /m^3 circulation
Steam cost	0.058 SRF* /ton
Power cost	0.252 SRF/MWh
*SRF: Standard refinery fuel value; 1 SRF = \$175	

TABLE 4. OPERATING ENERGY REQUIREMENTS			
Parameter	Units	Conventional	Vapor recompression
Reboiler steam	ton/h	79.69	None
Condenser cooling water	m^3/h	8,725	None
Auxiliary-condenser cooling water	m^3/h	None	1,295
Reflux pump duty	kW	287.3	201
Intermediate column transfer-pump duty	kW	400	None
Compressor duty	kW	None	7,045
Cooling water cost	\$million/yr	3.49	0.518
Steam cost	\$million/yr	6.47	None
Pumping cost	\$million/yr	0.139	0.07
Compressor power cost	\$million/yr	None	2.48
Total operating energy costs	\$million/yr	10.1	3.074

fic flow) with a steam-heated reboiler and water-cooled overhead condenser. The vapor-recompression-assisted distillation consists of an overhead vapor compressor, common reboiler-condenser and an auxiliary condenser. Table 1 gives details for the feed conditions, product specifications and utilities used for the distillation column designs. In a fluid catalytic cracking (FCC) unit of a petroleum refinery, the C_3-splitter column is installed downstream of a de-ethanizer column. Hence, the feed stream to the C_3 splitter essentially contains propane and propylene with negligible amounts of other components. Therefore, for simplicity, a binary system is considered. For simulation and other comparisons, the feed and product purity as well as recovery are kept the same for both the conventional and vapor-recompression cases.

The simulation model

Rigorous simulations were developed using steady-state simulation software. The thermodynamic systems are based on the Soave Redlich Kwong (SRK) equation of state. The built-in convergence method for distillation models is Russel's "Inside Out" routine [6] converging on error tolerance between inner simple loop and outer rigorous loop. Initial estimates are obtained from the shortcut distillation module, which uses the Fenske method to compute minimum trays required and the Underwood method for computing the minimum reflux ratio [7].

Conventional column simulation. Thermodynamically, it is desirable to operate the column at a pressure as low as possible for better separation. However, column pressure is also governed by the available utilities. A circulating cooling-water system used as the cold utility in this case study has a 32/38°C supply/return temperature. Considering a reasonable approach of 10°C for the overhead condenser design, the dew point of overhead vapors must be 42°C, which corresponds to 17 kg/cm^2 gage pressure. Thus, the column operating pressure is fixed at 17 kg/cm^2 gage based on the constraints of the cold-utility supply temperature.

A shortcut distillation model is set up for the given feed composition and required product specifications. The shortcut distillation module uses average relative volatility for the column and calculates the minimum reflux ratio required for the desired separation using the Underwood method [7]. For a column operating at 17 kg/cm^2 gage pressure, the minimum reflux ratio was calculated as 10.51. A rigorous distillation model is then set up based on the results of the shortcut distillation model. An optimum reflux ratio of 1.5 to 1.6 times the minimum reflux ratio is selected. Theoretical stages are varied from 120 to 240, and the reflux ratio — which in turn is represented by reboiler duty (mm kcal/h) here — is plotted against the number of theoretical trays. The reboiler duty or the reflux ratio decreases as the number of stages increases. As it can be noted from Figure 3, there is no significant reduction in the reboiler duty beyond 180 trays, hence the number of theoretical stages is fixed at 180. Theoretical trays are numbered from the top in the simulation model.

The feed tray location is selected so as to minimize reboiler and condenser duties. Figure 4 indicates that the optimum duty is achieved when the feed tray is located at tray 142. Finally, the column diameter of 6,250 mm is estimated based on a maximum of about 75% flooding. Results of the conventional column simulation are summarized in Table 2 for comparison.

Vapor-recompression-assisted column simulation. Steady-state simulators solve distillation column problems using various built-in algorithms that necessarily include reboilers and condensers as part of the distillation-column module itself. Thus, there is no need for the user to define the recycle streams (such as the reflux or vapors from the reboiler) or solve the distillation system by defining the calculation sequence manually in the simulation (using "tear stream algorithms"). When the vapor recompression system is used, the reboiler and condenser are one integrated unit (called the "common reboiler-condenser") rather than individual units.

The reboiler temperature approach

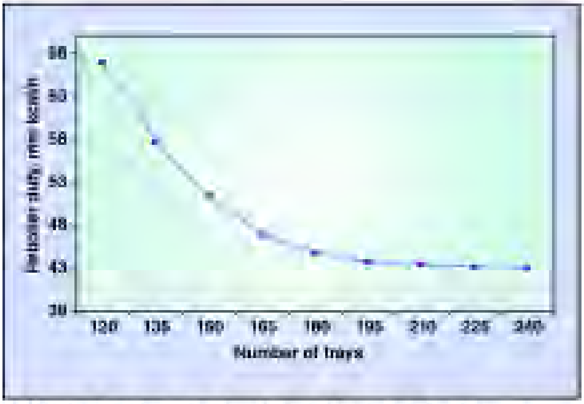

FIGURE 3. This plot shows that there is no significant reduction in the reboiler duty beyond 180 trays

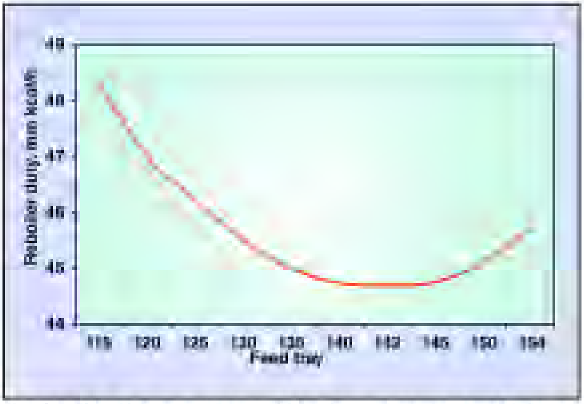

FIGURE 4. The simulation model for the conventional distillation system indicates that the optimum duty is achieved when the feed tray is located at tray 142

(the temperature difference between the reboiler outlet and the overhead compressed vapors entering the reboiler) is a major variable that affects compressor design. Available, standard distillation modules of simulators cannot be used in a straightforward manner. One possible way to model such a system is to use the conventional distillation-column module without the reboiler and condenser attached to it. A separate exchanger, as another flowsheet component, would then need to be selected to model the common reboiler-condenser. Also, separate flowsheet streams are required to connect the common reboiler-condenser to the distillation column. These flowsheet streams are thus not part of the column's built-in algorithm. With this approach, the user encounters a number of convergence difficulties even after matching the tear stream (the recycle stream to solve the closed loop) estimates close to reality. Apart from the common reboiler-condenser, a compressor needs to be defined as part of the external recycle loop. The process-flowsheet model's intrinsic recycle-loop-convergence method iterates the model until the specified heat-and-mass-balance related tolerances are achieved. Thus, convergence of the system will be highly iterative and it is also observed to diverge from the solution in each successive iteration, even if initial estimates are close to reality.

To overcome the above-stated simulation difficulties, an indirect modelling method is used [5]. A pseudostream is used to generate stream properties and rates for the stream leaving the top tray. This pseudostream becomes input for a standalone, sequentially executed compressor-exchanger recycle loop. The advantage of this approach is that it substitutes a recycle-stream convergence model with a once-through calculation. Multi-unit operations, such as the compressor-exchanger, can be solved independently without having any interference with the standard, distillation calculation module. Figure 5 illustrates the development of this model to define the vapor-recompression-distillation flowsheet.

Simulation of the vapor-recompression-distillation column uses the same feed conditions and meets the same product quality and recovery as given in Table 1. A main advantage to the vapor-recompression system is the possibility to operate the column with a lower operating pressure than a conventional column because cooling-water conditions no longer limit the system due to the common reboiler-condenser. The column operating pressure is dependent upon various optimization considerations.

The compressor is a key equipment item in the vapor recompression configuration. The overhead vapor stream is compressed to increase the condensing temperature to a temperature sufficiently greater than the temperature of the reboiler feed stream. Lower temperature differences increase the reboiler size, but also reduce the compression ratio and, hence, the size and power consumption of the compressor. The outlet pressure of the overhead vapor compressor is fixed, based on a reasonable 20°C approach temperature in the common condenser-reboiler. The column operating pressure, which is also the compressor suction pressure, is fixed based on the optimum compression ratio. The operating pressure was thus fixed as 12 kg/cm^2 gage.

A further reduction in column operating pressure requires an additional compressor stage and additional capital cost. The compressor discharge pressure is such so as to obtain a discharge temperature of about 70°C. Based on the heat duty requirement of the reboiler and the need to match the heat balances, the compressor discharge stream is split. Part of the stream is routed to the common reboiler-condenser and the balance is condensed in an auxiliary condenser.

There are a number of process variables that affect equipment sizes and the operating costs. Similar to the conventional column simulation, the minimum reflux ratio required to achieve the desired separation is calculated using the shortcut model operating at 13 kg/cm^2 abs pressure. The number of trays is then estimated using a reflux ratio of 1.5 to 1.6 times the minimum reflux ratio.

Presentation of results. The results for the conventional and vapor-recompression columns are presented in Table 2. For comparison purposes, a uniform basis of design is followed in both cases. The operating reflux ratio is kept at 1.5 to 1.6 times the minimum reflux ratio. Column diameters are chosen based on the same

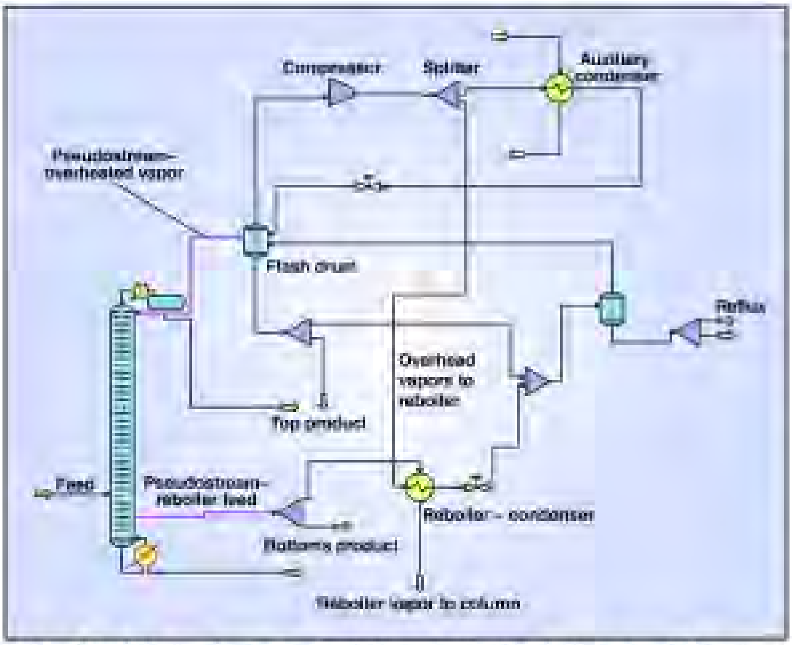

FIGURE 5. An indirect modeling method using a psuedostream was used to simulate vapor-recompression-assisted distillation

percentage (~75%) of maximum jet flooding in both cases. Simulation in both cases uses theoretical trays for comparison to demonstrate energy savings. Feed tray locations in both cases have been optimized to yield the lowest reboiler and condenser duties. Compressor power is calculated considering 75% polytropic efficiency.

By comparing the simulation results, the following can be seen for the vapor-recompression-assisted distillation:

- Distillation column diameter and height are lower and thus can be accommodated within one column
- The auxiliary condenser size is much smaller since it has a smaller duty
- The reflux pump is smaller in size
- The intermediate column-transfer pump is eliminated
- An additional compressor will be required

It is not the intention here to carry out a capital cost comparison, as it is dependent on various market conditions. However, it is believed that the energy savings (in other words, the operating cost) from the vapor-recompression system provide very high returns on investment.

Operating cost analysis. An operating cost analysis is used to demonstrate the energy savings in a vapor-recompression distillation system. The basis of the operating costs is presented in Table 3. The costs used are typical, and are benchmarked against U.S. Gulf Coast standard operating-plant data.

For the conventional distillation system, the operating energy costs consist of the reboiler steam cost, condenser cooling-water cost and reflux-pump power cost. Because the product pump's power cost is the same in both the cases, it is not considered for evaluation of cost gains. For the vapor recompression system, the operating energy costs include the cooling water cost for the auxiliary condenser and power costs for the reflux pump and compressor. In this system, no operating costs are associated with steam since the reboiler is heated by compressed column-overhead vapors.

The evaluated energy cost of a conventional distillation system with a steam reboiler and cooling-water condenser are shown to be higher than the vapor recompression system. Table 4 presents the major parameters contributing to operating costs used for cost analysis purposes. This operating cost comparison shows a net saving of about $7 million/yr. ■

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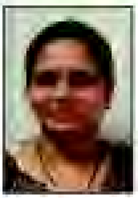

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Thermodynamic Analysis Of Electrolyte Systems

A methodical approach for modeling the behavior of aqueous electrolyte systems, with a practical example

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Thermodynamics cannot yield any information about the intermediate states of a given reacting system. These intermediate states are the subject matter of chemical kinetics, which studies reaction rates and mechanisms. Chemical kinetics will predict what chemicals are present while thermodynamics will predict the limits of distribution of those chemicals in the different phases [*1*]. The design and analysis of industrial systems usually involve simulating a steady state process by modeling its thermodynamic equilibrium to optimize the operating conditions.

Thermodynamic modeling of hydrocarbon systems has been extensively analyzed in literature and textbooks, while phase equilibria of aqueous systems have usually been ignored or briefly mentioned in broad terms. Thermodynamic modeling of electrolyte systems has been gaining momentum recently due to significant developments in a variety of chemical processes involving ionic solutions. The objective of this article is to simplify building thermodynamic models for simulating electrolyte systems.

A concise outline of modeling the thermodynamic equilibrium of electrolyte solutions is presented. The outline includes an overview of a number of useful activity-coefficient models as well as a new approach to express the thermodynamic equilibrium constants. Good quality expressions for thermodynamic equilibrium constants combined with a suitable activity coefficient model plus mass balance and electroneutrality relations can be used to simulate the behavior of ionic solutions under equilibrium. Methodical modeling of electrolyte systems is essential in accurately predicting the dynamics of their phase and chemical equilibria at different operating conditions.

Ionic equilibrium

The thermodynamic equilibrium constant for a specific reaction is defined as

$$K = \prod_i (a_i)^{\nu_i} = \exp\left(\frac{-\Delta G^\circ}{RT}\right) \quad (1)$$

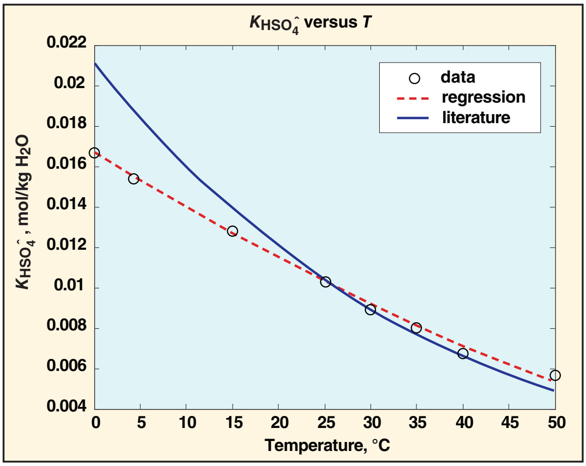

FIGURE 1. The equilibrium constant, K_{HSO4}, as a function of temperature

Accordingly, the thermodynamic equilibrium constant of the generic equilibrium reaction, $aA+bB \leftrightarrow cC+dD$ is given as

$$K = \frac{a_C^c \cdot a_D^d}{a_A^a \cdot a_B^b} \quad (2)$$

The equilibrium constants can be expressed as functions of temperature by integrating the van't Hoff equation with respect to temperature while assuming a constant heat capacity, which leads to Equation (3):

$$\ln K = \ln K^\circ - \frac{\Delta H^\circ}{R}\left(\frac{1}{T} - \frac{1}{T^\circ}\right) - \frac{\Delta Cp^\circ}{R}\left(\ln\frac{T^\circ}{T} - \frac{T^\circ}{T} + 1\right) \quad (3)$$

Reference-state thermodynamic properties of the reacting species are widely available in literature and can be used to evaluate the reference-state reaction thermodynamic properties above as follows:

$$\ln(K^\circ) = \frac{-\sum_i \nu_i G_i^\circ(T^\circ)}{RT^\circ} \quad (3a)$$

$$\Delta Cp^\circ = \sum_i \nu_i Cp_i^\circ \quad (3b)$$

$$\Delta H^\circ = \sum_i \nu_i H_i^\circ \quad (3c)$$

$$\Delta G^\circ = \sum_i \nu_i G_i^\circ \quad (3d)$$

A more accurate version of the equilibrium constant relation can be obtained by substituting a temperature-dependent heat-capacity function above, $Cp_i(T)$, integrating it, and then proceeding with the same steps to get to the

NOMENCLATURE

A Debye–Hückel constant for osmotic coefficients, $(kg\ H_2O/mol)^{1/2}$
a Molality based activity
B Interaction term, $kg\ H_2O/mol$
C Interaction term, $(kg\ H_2O/mol)^2$
Cp Partial molar specific heat, J/(mol·K)
D′ Dielectric constant of water
D Interaction term, $kg\ H_2O/mol$
e Electron charge = 1.602×10^{-19}, C
E Constant in self-interaction parameter equation, $kg\ H_2O/mol$
f Pitzer's electrostatic function or vapor phase fugacity
F Constant in self-interaction parameter equation, $kg\ H_2O{\cdot}K/mol$
G Partial molar Gibbs free energy, J/mol
H Partial molar enthalpy, J/mol
I Ionic strength, $mol/kg\ H_2O$
k Boltzmann constant = 1.381×10^{-23}, J/K
k_i Setschenow coefficient
K Dissolution equilibrium constant
Kaq Vapor–liquid equilibrium constant
Ksp Solubility product
m Molality, $mol/kg\ H_2O$
MW Molecular weight, kg/mol
n Number of moles, mol
N_A Avogadro's number = $6.022137\ 10^{+23}$, 1/mol
P Pressure, Pa
pH pH of liquid
R Ideal gas constant = 8.314 J/mol·K
T Temperature, K
X Interactions summation
x Mole fraction in solid
Y Interactions summation
Z Interactions summation, $mol/kg\ H_2O$
z Ionic charge
ΔCp Molar specific heat of dissolution or solubility, J/(mol·K)
ΔG Molar Gibbs free energy of dissolution or solubility, J/mol
ΔH Molar enthalpy of dissolution or solubility, J/mol
β^0 Interaction parameter, $kg\ H_2O/mol$
β^1 Interaction parameter
γ Molality based activity coefficient
ϵ_0 Permittivity of free space = 8.854×10^{-12}, $C^2/(N{\cdot}m^2)$
μ Chemical potential, J/mol
υ Stoichiometric coefficient, J/mol
ρ Mass density, kg/L

TABLE 1. EXPEDIENT EVALUATION OF VARIOUS ELECTROLYTE ACTIVITY COEFFICIENT MODELS

Model	Expression for ionic activity coefficient	Expression for molecular activity coefficient	Expression for water activity	Accounts for ion-ion interactions	Accounts for ion-molecule interactions	Accounts for molecule-molecule interactions	Concentration range
Debye-Hückel [*3*]	Yes	No	No	Yes	No	No	I < 0.001 M
Extended Debye-Hückel [*11*]	Yes	No	No	Yes	No	No	I < 0.1 M
Bromley [*12*]	Yes	No	Yes	Yes	No	No	I < 6 M
Meissner [*13, 14*]	Yes	No	Yes	Yes	No	No	I < 15 M
Pitzer [*15, 16*]	Yes	No	Yes	Yes	No	No	I < 6 M
Edwards-Maurer-Newman-Prausnitz [*6, 7*]	Yes	Yes	Yes	Yes	Yes	Yes	I < 6 M
Beutier-Renon [*17, 18*]	Yes	Yes	Yes	Yes	Yes	Yes	
Chen [*19, 20*]	Yes	Yes	Yes	Yes	Yes	Yes	

equilibrium constant relation. Another alternative can be used to obtain a more accurate version of the equilibrium constant relation above if experimental data of the equilibrium constant at various temperatures are available. $\Delta Cp°$ and $\Delta H°$ can be used as adjustable parameters to fit the data to the above equilibrium-constant relation by means of nonlinear regression. This will compensate for the temperature-independent heat capacity assumption used to develop that equation, which will result in better estimates of the equilibrium constants. Figure 1 illustrates this improvement by comparing two equilibrium-constant predictions to experimental data for the disassociation reaction of the hydrated sulfate ion, HSO_4^{-1}. Both predictions were produced by the above-derived equilibrium constant relation; however, one used published literature values for $\Delta Cp°$ and $\Delta H°$ and the other one used adjustable parameters for $\Delta Cp°$ and $\Delta H°$.

Ionic activity

In 1887, Svanté Arrhenius [*2*] presented his theory of electrolytic dissociation of solute into negatively and positively charged ions. He assumed that the distribution and motion of ions in a solution is independent of the ionic interaction forces. Experimental work showed that Arrhenius' theory holds only for weak electrolytes, and that electrostatic forces between ions must be considered, especially for strong electrolytes.

In 1923, Peter Debye and Erich Hückel [*3*] presented their theory of inter-ionic attractions in electrolyte solutions. As electrolyte dissociation in solutions increases, ion concentration also increases resulting in smaller distance and greater electrostatic force between ions. The strength of this Coulombic interaction between ions must therefore be considered in modeling thermodynamic equilibria of electrolyte systems.

Ionic strength is a measure of the average electrostatic interactions among ions in an electrolyte. Lewis and Randall [*4*] defined the ionic strength as one half the sum of the terms obtained by multiplying the molality of each ion by its valence squared:

$$I = \frac{1}{2}\sum_i m_i z_i^2 \tag{4}$$

The chemical potential of species i is expressed in terms of its activity as follows:

$$\mu_i(T) = \mu_i^\circ(T) + RT\ln(a_i) \tag{5}$$

Where the standard state is a hypothetical solution with molality $m°$ for which the activity coefficient is unity. Activity is a way for expressing the effective concentration of species to account for their deviation from ideal behavior. Activity can be applied to different concentration scales, such as molality, molarity or fractional scales; however, molality is the most common concentration scale for electrolyte solutions. Molality-based activity is defined as $a_i = \gamma_i(m_i / m^\circ)$, where $m°$ is the reference-state unit molality; however, $m°$ is normally omitted with the understanding that both the activity and the activity coefficient are dimensionless. Molality-based activity is then written as follows:

$$a_i = \gamma_i m_i \tag{6}$$

Ionic activity coefficient models

The Debye–Hückel theory [3] presented in 1923 paved the way for modeling electrolytes by accounting for the electrostatic forces present in aqueous solutions. Many aqueous electrolyte thermodynamic models based on the Debye–Hückel theory have been developed since then, with most models containing adjustable interaction parameters to fine tune their analytical approach.

Electrolyte activity is very challenging to model due to the various interaction forces present between the differently charged and differently sized molecules. Having a clear objective is essential in selecting the appropriate model to simulate the activity of electrolyte solutions. The appropriate model is selected based on its validity range, interaction mode characterization, interaction parameters availability, and mathematical complexity. In addition, some models can only express the activity of ionic species and do not include expressions for water or molecular species.

Table 1 compares several electrolyte activity coefficient models. If easy convergence is preferred, a simple model can be selected to express the activity of ionic species combined with a simple relation, for instance the Setschénow equation [5], $\ln(\gamma_i) = k_i m_i$, to express the activity of molecular species. If consistency is preferred, a comprehensive model should be selected to express the activity of all species. Furthermore, the simulated system should always be within validity range of the selected activity model.

The Edwards-Maurer-Newman-Prausnitz Pitzer-based model [6, 7] is a comprehensive self-contained activity coefficient model that handles both charged and uncharged species in a multi-component solution. It can be unequivocally incorporated into electrolyte thermodynamic models to write the activity coefficients of all ions and molecules due to its objective and straightforward approach to obtaining the interaction parameters. Accordingly, the model is selected in this article to express the activity coefficients of the simulated electrolyte system. The Edwards-Maurer-Newman-Prausnitz Pitzer-based model is considered viable for aqueous solutions with ionic strengths up to 6 mol/kg H_2O and for temperatures ranging from 0 to 170°C.

The activity coefficients of all ions and molecules in solution are given by the following:

$$\ln\gamma_i = z_i^2 \cdot f + 2\cdot X_i + z_i^2 \cdot Y \tag{7}$$

The Edwards–Maurer–Newman–Prausnitz Pitzer–based model also offers an expression for water activity in a multi–component solution:

$$\ln a_{H_2O} = MW_{H_2O}\cdot\left[\frac{2\cdot A\cdot I^{3/2}}{1+1.2\cdot\sqrt{I}} - Z - \sum_{i\neq H_2O} m_i\right] \tag{8}$$

The included electrostatic functions of the activity coefficient model are defined by the following equations:

$$A = \frac{1}{3}\cdot\sqrt{2000\cdot\pi\cdot N_A\cdot\rho_{H_2O}}\cdot\left[\frac{e^2}{4\cdot\pi\cdot\varepsilon_0\cdot D'\cdot k\cdot T}\right]^{3/2} \tag{9}$$

$$f = -A\cdot\left[\frac{\sqrt{I}}{1+1.2\cdot\sqrt{I}} + \frac{2}{1.2}\cdot\ln\left(1+1.2\cdot\sqrt{I}\right)\right] \tag{10}$$

$$Y = \sum_{i\neq H_2O} Y_i \tag{11}$$

$$Z = \sum_{i\neq H_2O} Z_i \tag{12}$$

The colligative properties of the activity coefficient model are given as follows:

$$X_i = \sum_{j\neq H_2O} B_{i-j}\cdot m_j \tag{13}$$

$$Y_i = \sum_{j\neq H_2O} C_{i-j}\cdot m_i\cdot m_j \tag{14}$$

$$Z_i = \sum_{j\neq H_2O} D_{i-j}\cdot m_i\cdot m_j \tag{15}$$

The interaction terms of the activity coefficient model are given as follows:

$$B_{i-j} = \beta_{i-j}^0 + \frac{\beta_{i-j}^1}{2\cdot I}\cdot\left[1-\left(1+2\cdot\sqrt{I}\right)\cdot\exp\left(-2\cdot\sqrt{I}\right)\right] \tag{16}$$

$$C_{i-j} = \frac{\beta_{i-j}^1}{4\cdot I^2}\cdot\left[-1+\left(1+2\cdot\sqrt{I}+2\cdot I\right)\cdot\exp\left(-2\cdot\sqrt{I}\right)\right] \tag{17}$$

$$D_{i-j} = \beta_{i-j}^0 + \beta_{i-j}^1\cdot\exp\left(-2\cdot\sqrt{I}\right) \tag{18}$$

Edwards and others [6, 7] proposed a simplified approach to estimate the interaction parameters of the activity coefficient model in a multi-component solution. Their approach can be summarized as follows:

1. If i and j are ions of like charge, $\beta^0_{i-j} = \beta^1_{i-j} = 0$.
2. If i or j is a molecular species, $\beta^1_{i-j} = 0$.
3. If i and j are molecular species, $\beta^0_{i-j} = \frac{1}{2} \cdot \left(\beta^0_{i-i} + \beta^0_{j-j}\right)$.
4. Molecular self–interaction parameter is a function of temperature: $\beta^0_{i-i} = E + F/T$.
5. The remaining ion-ion and ion-molecule interaction parameters are estimated using Bromley's theory of the additivity of single ion interactions [*12*] given here:

$\beta^0_{i-j} = \beta^0_i + \beta^0_j$ and $\beta^1_{i-j} = \beta^1_i + \beta^1_j$.

Single interaction parameters are obtained by applying Bromley's additivity theory to the binary interaction parameters given by Pitzer and Mayorga [*8*] at 25°C for strong electrolytes. β^0_{Na} and β^1_{Na} are arbitrarily set to zero to accomplish this separation.

Solid-liquid equilibria

Electrolytes dissolve in some solvents until they form a saturated solution of their constituent ions in equilibrium with the undissolved electrolytes. In a saturated solution, electrolytes continue to dissolve, and an equal amount of ions in the solution keep combining to precipitate as a solid. Simple dissociation reactions can be represented as follows:

$$C_m A_n (s) \underset{Precipitation}{\overset{Dissolution}{\longleftrightarrow}} mC^{c+}(aq) + nA^{a-}(aq)$$

The equilibrium constant for a dissolution reaction is called the solubility product, and is given by the above thermodynamic equilibrium constant, Equation (1). The solubility product of the given arbitrary dissolution reaction is then

$$Ksp = \prod_i (a_i)^{v_i} = \frac{(a_C)^m (a_A)^n}{(a_{C_m A_n})} \qquad (\mathbf{19})$$

The activity of undissolved electrolytes or any other solid is usually expressed on fractional scale by Equation (20):

$$a_i = \gamma_i x_i \qquad (\mathbf{20})$$

For slightly soluble electrolytes, deviation from ideality is diminutive and the value of the activity coefficient approaches unity. The above solubility product relation can then be rewritten:

$$Ksp = \frac{(a_C)^m (a_A)^n}{(x_{C_m A_n})} \qquad (\mathbf{21})$$

Notice that *Ksp* at the standard conditions can be calculated by using the definition of the equilibrium constant or by using the van't Hoff equation [*21*] given above.

Vapor-liquid equilibria

Some gases dissolve in electrolyte solutions and establish an equilibrium with the undissolved gas. As before, this can be represented as follows:

$$Kaq = \frac{a^L_i}{a^V_i} \qquad (\mathbf{22})$$

a^L_i can be obtained using the liquid-phase activity relation given above, and a^V_i is related to the partial pressure by its fugacity coefficient as follows:

$$a^V_i = f_i P_i \qquad (\mathbf{23})$$

Notice that *Kaq* at the standard conditions can be calculated by using the definition of the equilibrium constant or by using van't Hoff equation [*21*] given above.

Auxiliary relations

The hydrogen ion activity in a solution is an important concept in many chemical and biological processes. The magnitude of this activity is measured by the pH, where

$$pH = -\log_{10}\left(a_{H^+} \cdot \rho_{H_2O}\right) \qquad (\mathbf{24})$$

Note that the mass density of water was used to convert the activity concentration scale from molality to molarity as required by the pH definition. In other words, pH is the negative logarithm (base 10) of the hydrogen ion activity given on a molarity scale. The mass density of water can be calculated as a function of temperature by the following [*9*]:

$$\rho_{H_2O} = 1 - \frac{(T+16)\cdot(T-277)^2}{(508929)\cdot(T-205)} \qquad (\mathbf{25})$$

The electrostatic forces between different ions in a solution depend on the polarity of the solvent. The dielectric constant of a solvent is a measure of its polarity and is widely used in modeling molecular interactions. The Dielectric constant of water can be calculated as a function of temperature by Equation (26) [*2*]:

$$D' = 305.7 \cdot \exp\left(-\exp(-12.741 + 0.01875 \cdot T) - \frac{T}{219}\right) \qquad (\mathbf{26})$$

A charge balance is needed to satisfy the electro-neutrality condition as shown here:

$$\sum_i m_i z_i = 0 \qquad (\mathbf{27})$$

Simulation algorithm

Thermodynamic equilibrium modeling of electrolyte systems begins with considering their major equilibrium reactions, which describe the dissolution of acids and bases as well as the precipitation of salts. Subsequently, a material balance comprising all the species of the considered equilibrium reactions is formulated using their molalities and molecular weights. The material balance is interlocked with a charge balance using the electro–neutrality relation given in Equation (27). The equilibrium constants of the considered equilibrium reactions are evaluated at a given design temperature using Equation 3 and are expressed in terms of activities using Equations (1), (21) and (22). The activity of each species is related to its molality using its activity coefficient as in Equations (6), (20) and (23). Finally, the activity of water and the activity coefficients of all species are computed using a suitable activity coefficient model, Equations (7–18), and its auxiliary relation, Equations (4) and (24–26).

Simulation is accomplished by building a computer code based on the above indicated equations and solving them simultaneously. Executing that computer code will probably require providing initial guesses to some system variables due to the integrated nature of its equations. Providing discreet guesses is very essential to the convergence of the code. The mathematical complexity of the code increases significantly with increasing difference in the value of its equilibrium constants. In addition, very fast and very slow equilibrium reactions do not disturb the equilibrium; therefore, they can be ignored.

A case study

Phosphoric acid is produced via the dihydrate process by reacting phosphate rock, principally tricalcium phosphate, with sulfuric acid and water as follows:

$$Ca_3(PO_4)_2 + 3H_2SO_4 + 6H_2O \longrightarrow 2H_3PO_4 + 3CaSO_4 \cdot 2H_2O$$

The process involves the co–precipitation of gypsum as well as dicalcium phosphate dihydrate, known as DCPD. The precipitation of DCPD is considered a phosphate loss and it is desired to model the reacting system to study the controlling variables of that loss.

The model is built based on the following reacting system:

$$H_3PO_4 \longleftrightarrow H^+ + H_2PO_4^-$$

$$H_2PO_4^- \longleftrightarrow H^+ + HPO_4^{2-}$$

$$HSO_4^- \longleftrightarrow H^+ + SO_4^{2-}$$

$$CaHPO_4 \cdot 2H_2O \longleftrightarrow Ca^{2+} + HPO_4^{2-} + 2H_2O$$

$$CaSO_4 \cdot 2H_2O \longleftrightarrow Ca^{2+} + SO_4^{2-} + 2H_2O$$

The slow dissolution of H_2O and HPO_4^{2-} and the fast dissolution of H_2SO_4 are ignored. The total phosphate molality and the total sulfate molality are known parameters defined as follows:

$$TPM = m_{H_3PO_4} + m_{H_2PO_4^-} + m_{HPO_4^{2-}}$$

$$TSM = m_{HSO_4^-} + m_{SO_4^{2-}}$$

The liquid phase mass balance is given below:

$$M_{TPM} = m_{H_3PO_4} \cdot MW_{H_3PO_4} + m_{H_2PO_4^-} \cdot MW_{H_2PO_4^-} + m_{HPO_4^{2-}} \cdot MW_{HPO_4^{2-}}$$

$$M_{TSM} = m_{HSO_4^-} \cdot MW_{HSO_4^-} + m_{SO_4^{2-}} \cdot MW_{SO_4^-}$$

$$M_{Other} = m_{H^+} \cdot MW_{H^+} + m_{Ca^{2+}} \cdot MW_{Ca^{2+}}$$

$$M_{Total} = M_{H_2O} + M_{TPM} + M_{TSM} + M_{Other}$$

M_i is the total mass of i per the total mass of water in the liquid; therefore, M_{H2O} equals 1 and M_{Total} is greater than 1. The electro–neutrality condition is a required constraint given by the following equation:

$$z_{H_2PO_4^-} m_{H_2PO_4^-} + z_{HPO_4^{2-}} m_{HPO_4^{2-}} + z_{HSO_4^-} m_{HSO_4^-} + z_{SO_4^{2-}} m_{SO_4^{2-}} + z_{H^+} m_{H^+} + z_{Ca^{2+}} m_{Ca^{2+}} = 0$$

Neglecting the presence of impurities, the solid-phase mass balance is given here:

$$x_{DCPD} + x_{Gypsum} = 1$$

The equilibrium constants of model reactions are defined by the following:

$$K_{H_3PO_4} = \frac{a_{H_2PO_4^-} \cdot a_{H^+}}{a_{H_3PO_4}}$$

$$K_{H_2PO_4^-} = \frac{a_{HPO_4^{2-}} \cdot a_{H^+}}{a_{H_2PO_4^-}}$$

$$K_{HSO_4^-} = \frac{a_{SO_4^{2-}} \cdot a_{H^+}}{a_{HSO_4^-}}$$

$$Ksp_{DCPD} = \frac{a_{HPO_4^{2-}} \cdot a_{Ca^{2+}} \cdot a_{H_2O}^{\;2}}{a_{DCPD}}$$

$$Ksp_{Gypsum} = \frac{a_{SO_4^{2-}} \cdot a_{Ca^{2+}} \cdot a_{H_2O}^{\;2}}{a_{Gypsum}}$$

Activities are given by $a_i = \gamma_i \cdot m_i$ for liquid-phase ions, and by $a_i = \gamma_i \cdot x_i$ for solid-phase molecules. The equilibrium constants are expressed as functions of temperature by:

$$\ln K_{H_3PO_4} = \ln K^\circ_{H_3PO_4} - \frac{\Delta H^\circ_{H_3PO_4}}{R}\left(\frac{1}{T} - \frac{1}{T^\circ}\right) - \frac{\Delta Cp^\circ_{H_3PO_4}}{R}\left(\ln\frac{T^\circ}{T} - \frac{T^\circ}{T} + 1\right)$$

$$\ln K_{H_2PO_4^-} = \ln K^\circ_{H_2PO_4^-} - \frac{\Delta H^\circ_{H_2PO_4^-}}{R}\left(\frac{1}{T} - \frac{1}{T^\circ}\right) - \frac{\Delta Cp^\circ_{H_2PO_4^-}}{R}\left(\ln\frac{T^\circ}{T} - \frac{T^\circ}{T} + 1\right)$$

$$\ln K_{HSO_4^-} = \ln K^\circ_{HSO_4^-} - \frac{\Delta H^\circ_{HSO_4^-}}{R}\left(\frac{1}{T} - \frac{1}{T^\circ}\right) - \frac{\Delta Cp^\circ_{HSO_4^-}}{R}\left(\ln\frac{T^\circ}{T} - \frac{T^\circ}{T} + 1\right)$$

$$\ln K_{DCPD} = \ln K^\circ_{DCPD} - \frac{\Delta H^\circ_{DCPD}}{R}\left(\frac{1}{T} - \frac{1}{T^\circ}\right) - \frac{\Delta Cp^\circ_{DCPD}}{R}\left(\ln\frac{T^\circ}{T} - \frac{T^\circ}{T} + 1\right)$$

$$\ln K_{Gypsum} = \ln K^\circ_{Gypsum} - \frac{\Delta H^\circ_{Gypsum}}{R}\left(\frac{1}{T} - \frac{1}{T^\circ}\right) - \frac{\Delta Cp^\circ_{Gypsum}}{R}\left(\ln\frac{T^\circ}{T} - \frac{T^\circ}{T} + 1\right)$$

Experimental data of equilibrium constants at various temperatures of model reactions were regressed using the above relations yielding the adjusted values of $\Delta Cp°$ and $\Delta H°$ given in Table 2.

TABLE 2. EXPERIMENTAL AND REGRESSED VALUES FOR THE EQUILIBRIUM CONSTANT RELATIONS OF THE CASE STUDY			
Equilibrium Reaction	**Experimental *K°***	**Adjusted ΔCp°**	**Adjusted ΔH°**
$H_3PO_4 \longleftrightarrow H^+ + H_2PO_4^-$	7.112×10^{-3}	-155	-7,663
$H_2PO_4^- \longleftrightarrow H^+ + HPO_4^{2-}$	6.340×10^{-8}	-249	4,034
$HSO_4^- \longleftrightarrow H^+ + SO_4^{2-}$	1.030×10^{-2}	-310	-16,928
$CaSO_4 \cdot 2H_2O \longleftrightarrow Ca^{2+} + SO_4^{2-} + 2H_2O$	4.220×10^{-5}	-494	4,338
$CaHPO_4 \cdot 2H_2O \longleftrightarrow Ca^{2+} + HPO_4^{2-} + 2H_2O$	2.513×10^{-7}	-879	-3,050

TABLE 3. SINGLE INTERACTION PARAMETERS FOR THE SPECIES OF THE CASE STUDY		
Species	β^0	β^1
H_3PO_4	0.0477	0.0677
$H_2PO_4^-$	-0.053	0.0396
HPO_4^{2-}	-0.058	1.4655
HSO_4^-	0.0257	0.838
SO_4^{2-}	0.0196	1.113
H^+	0.101	0.0281
Ca^{2+}	0.2394	1.3476

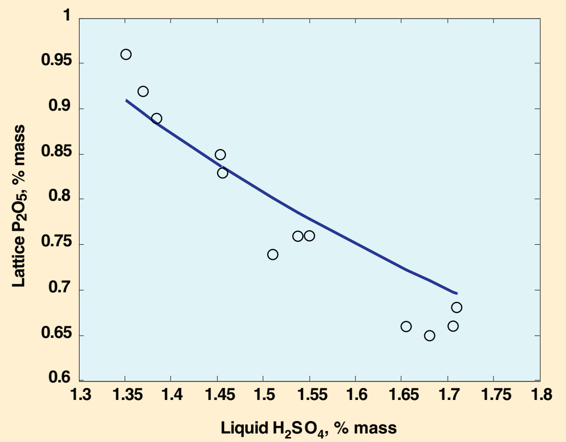

FIGURE 2. This graph shows the phosphate loss at 78.50°C and 31.15% solution phosphates

The solid phase is assumed to be ideal; thus, $\gamma_{Gypsum} = \gamma_{DCPD} = 1$. The Edwards-Maurer-Newman-Prausnitz Pitzer-based model detailed above is used to express the activity coefficients of all solution ions and molecules. Table 3 lists the single interaction parameters obtained by applying Bromley's additivity theory to the Pitzer's binary interaction parameters as was mentioned earlier. The molecular self–interaction parameter of phosphoric acid has been determined in previous work and is given by $\beta^o_{H3PO4-H3PO4} = 0.3609 + 73.1537/T$.

A computer code was developed to simultaneously solve the above equations describing the developed model. In one simulation, the sulfate level was varied at typical manufacturing conditions to study its effect on the phosphate loss yielding matching results to experimental data as shown in Figure 2. A detailed analysis of this case study has been carried out by Abutayeh and Campbell [*10*].

One way to optimize the dihydrate process is to minimize phosphate loss by shifting system equilibrium toward more dissolution and less precipitation of DCPD. The preceding model can be employed to carry out different simulations using several inputs of temperatures and liquid-phase sulfuric-acid contents to find their optimum operating values. Decreasing temperature and increasing liquid-phase sulfuric-acid content were found to minimize phosphate loss; however, this needs to be balanced with other cost contributing factors.

The Edwards-Maurer-Newman-Prausnitz Pitzer-based model has been successfully used to model many other industrial electrolyte systems. Models representing NH_3–H_2O, CO_2–H_2O, and NH_3–CO_2–H_2O systems have been developed and reconciled with experimental data [*2*]. The Edwards-Maurer-Newman-Prausnitz Pitzer-based model was also incorporated into a detailed FORTRAN code simulating the complex NH_3–CO_2–H_2S–H_2O–KOH–NaOH reactive absorption process yielding results that were in very good agreement with data taken from a gas purification pilot plant [*23*]. ■

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Condition Monitoring for Rotating Machinery

This valuable insight into the performance of pumps and compressors will help improve operation

Amin Almasi
Rotating Machine Consultant

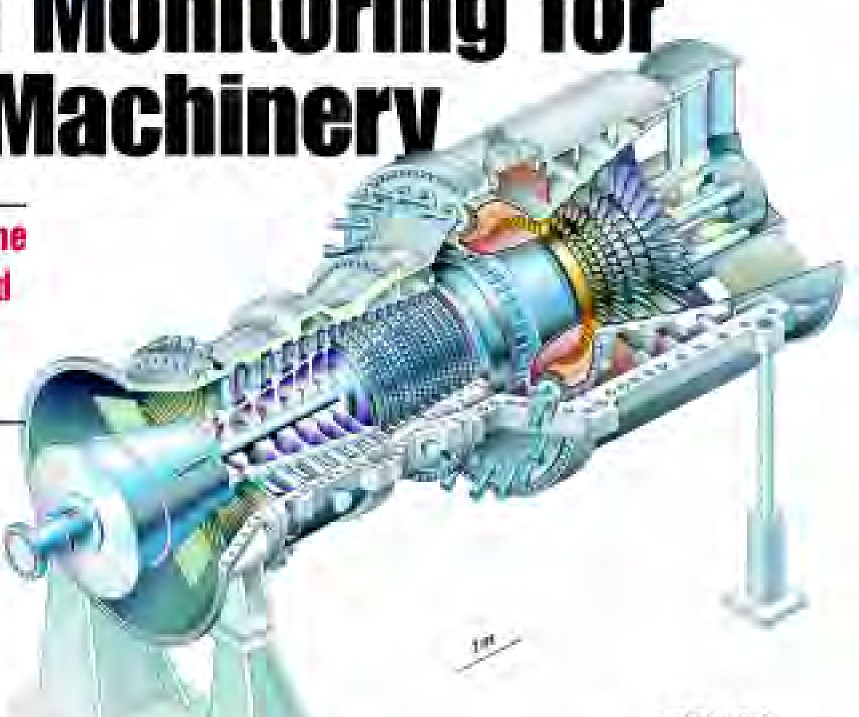

FIGURE 1. Shown here is an example of a complex gas turbine in a CPI facility. Modern rotating machines are very complex and contain many stages and auxiliaries. Stage degradation and related problems have a cumulative effect. A degraded stage creates different exit conditions and each subsequent stage then operates further away from its design point. Ultimately, degradation at each stage or component will force all stages to work at off-optimum efficiencies

Rotating machines, such as pumps, compressors, gas turbines, steam turbines and electric motors, play crucial roles in most chemical process industries (CPI) facilities. Increasingly, advanced condition monitoring is being used to improve the operation and maintenance of these workhorse components. The use of well-designed condition-monitoring systems, predictive-maintenance strategies and failure root-cause analysis can improve equipment reliability and bring numerous other technical and commercial benefits, performance improvements and cost savings.

The goal of any profitable process plant is to operate rotating machinery with maximum reliability and efficiency, and minimum operating and maintenance costs. The first step is to ensure proper specification and design of rotating machinery. An important aspect of specification is proper clarification of details up front — prior to the bidding phase and purchase-order placement.

Increasingly, once the equipment is in operation, CPI facilities are implementing condition monitoring and predictive-maintenance programs to ensure that un-spared (critical) rotating machines can be operated effectively, without an unscheduled shutdown. At the same time, it should be noted that in general, manufacturers of rotating machines maximize their own profit by producing machinery that meets the user's project specifications and applicable codes at the lowest possible cost. The manufacturers' main focus is typically on ensuring performance that meets the warranty conditions. Thus, machine manufacturers often do not initiate additional improvements that could extend reliability and trouble-free operation for a period beyond that of the warranty period. Many manufacturers believe they cannot remain competitive (or perhaps even stay in business) if they were to design and produce equipment that could ensure reliable, trouble-free operation for a longer period (say 20 or 30 years). This makes it even more important for operators to exercise great care, through the use of condition monitoring and predictive maintenance efforts, to extend the life of these costly components.

When carrying out reliability studies and condition monitoring, rotating machines should be viewed as a complete system, including the driver, transmission system, coupling, all auxiliaries (such as the gear unit, if applicable), lubrication oil system, cooling system (if any) and seal system. Such a rotating machine package, regardless of type is always customized to meet the operator's site-specific requirements, which include upstream and downstream process facilities, site conditions, the machine's unique battery limits and piping arrangement, foundation details and more. Because every rotating-machinery

FIGURE 2. Disassembly of a gear unit for inspection allows operators to inspect gear-contact patterns after installation or during operation. Under ideal conditions, the contact pattern across each tooth will be uniform around each gear (indicating full contact). However, machining, assembly errors, distortion of the gear unit housing and misalignment can create problems. An improper gear-set contact pattern creates high stresses on the gear teeth

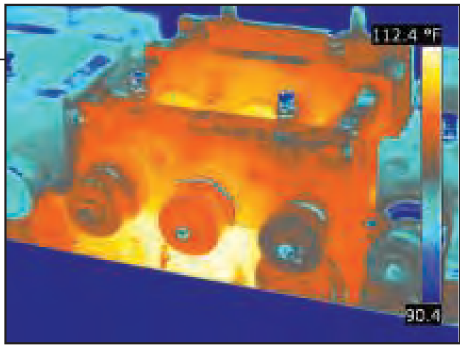

FIGURE 3. Thermographic monitoring of mechanical machines is a useful tool during condition monitoring. Improper lubrication, misalignments, and failing parts are just a few of the common problems that can be identified using an infrared scan of mechanical equipment. Properly scheduled thermal inspections can help to provide early detection of problems and thus avoid costly unscheduled shutdowns

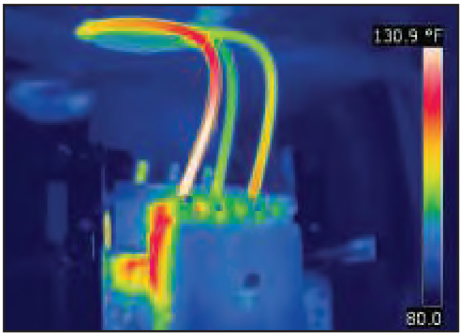

FIGURE 4. Infrared thermographic inspections of electrical auxiliary equipment related to plant machinery can reveal "hot spots" that are commonly found in equipment prior to failure. Loose connections, faulty components, overloaded parts and high friction are some of common problems that can be found during a thermographic scan. All "exceptions" should be properly documented with thermal and digital images that can be used in the condition monitoring

package is essentially a customized enterprise, each machine produces its own unique "operational" signature. Figure 1 shows an example of a a complex rotating machine in a CPI setting. Figure 2 shows an example of a gear unit that has been taken apart for inspection.

Condition monitoring

Condition monitoring is carried out by analyzing trends in data related to key operating parameters. It requires the strategic use of suitable sensors to track relevant parameters, and the establishment of normal (baseline) data so that excursions between measured and baseline values can be recognized quickly and analyzed to identify condition changes.

The major components that can benefit from condition monitoring include bearings (including radial and thrust bearings), seals and packings, rotors (shaft or crankshaft mechanism) and auxiliaries. Ideally, baseline information should be collected "early in the life" of the machine components, so that it captures "ideal" operating conditions (not conditions that may have already been subject to some degradation). Too often, operators fail to collect data related to baseline operating conditions because the initial weeks or months of operation tend to be very busy. A lack of adequate baseline data will seriously reduce the value of condition monitoring since there is no reference information available for comparing and interpreting the operating data. Revised baseline data should also be collected after any major maintenance overhaul.

What to look for

Problematic machines often generate high vibration (dynamic forces) or hot spots. This occurs because machines or components that are operating inefficiently or with a problem often run "hot," causing components to wear out or fail prematurely. Temperature sensors and infrared thermometers are also essential parts of monitoring rotating machines and auxiliary equipment. Figures 3 and 4 show examples of thermographic monitoring results.

Rotating machines do not fail randomly. There are root-causes for each failure mode. To effectively prevent failure, the reasons leading up to potential failure must be known. To carry out effective failure analysis, proper measurement parameters, sensors, and setpoints should be defined for all key components. Being aware of the major reasons for failure and observing the conditions that could lead to failure enable operators to address the issue and improve reliability.

Major failure categories include the following:

- Process condition changes, which may include changes in either operating conditions or operating procedures and represents the most important cause of rotating machine failure
- Design, fabrication, assembly, installation and commissioning issues and problems
- Machine wear-out

All rotating machines react to operating conditions in the facility. Individual types of machinery will adjust in different ways.

For instance, for positive-displacement rotating machines (such as reciprocating compressors, screw compressors, screw pumps and others), the adjusted flowrate of the machine is not significantly affected by the process system. Thus, flowrate is a very good parameter to monitor over time, to assess the health of positive-displacement machines and determine if any problems or wear-out have arisen.

FIGURE 5. The root cause of rotating machine component failure is often found in the supporting auxiliary system, particularly the oil or cooling systems. Since change in the coolant supply temperature is a common cause of many machine failures, coolant temperature sensors (shown here) should be used

Dynamic machines (such as centrifugal compressors, axial compressors, centrifugal pumps and others) use high-speed rotating parts (such as blades or impellers) to increase the velocity of the fluid, and then use the velocity of the fluid to increase the fluid pressure. They typically have variable flow and pressure characteristics. As a result, flowrate can vary with changing operating conditions, such as differential pressure or fluid density, and thus the reliability of dynamic rotating machines (as well as the reliability of their drivers and auxiliaries) is directly affected by the process and operating conditions. The rotating machine loading, transmitted torques, driver power and auxiliary system operation are affected by the process. For example, process requirements that call for a higher flowrate may result in driver overload.

The reliability of machine components (such as bearings, seals and others) is directly related to auxiliary systems. Changes in the auxiliary systems supplied fluid temperature (such as the temperature of lubrication oil or cooling fluid supplied to the machine) resulting from a change in the cooling water temperature (for water-cooled systems) or in the ambient-air temperature change (for air-cooled systems) is a common root cause of component failure. Figure 5 shows the placement of a coolant temperature sensor in a rotating machine.

Failure of machines and components often occurs because the equipment is subjected to conditions that exceed its design values. Most often, machinery damage and wear occur during transient conditions, such as startup or shutdown. During these times, the equipment is often subjected to rapid temperature, pressure and speed changes.

In many cases, the root-cause of mechanical damage to dynamic rotating machines is that the head required by the process system has exceeded the capability of the machine. For a given impeller vane slope, the head produced by a centrifugal pump is a function of impeller diameter and impeller speed. Once the impeller is designed and fabricated, it can produce only one value of head for a given shaft speed and flowrate. The only circumstance that can cause a lower value of head is if the machine has experienced mechanical damage or has become fouled. Thus pressure (particularly differential pressure) is a very good parameter to monitor in assessing dynamic machine health.

Based on experience, the most common root cause of failure is changes to process or operating conditions. The second most-common reason relates to installation and commissioning issues.

Design or manufacturing problems rank third, but this type of problem usually shows up shortly after startup. The main cause of design problems is that the component has not been designed for the specified operating condition. Component wear is most often the result of the problem — not the root cause of the problem. Excessive wear of the bearing, seal, wear-ring, or similar item usually results from process condition changes. Bearings often suffer as a result of assembly or installation problems.

In rotating machine applications, online condition-monitoring systems allow operators to monitor key operating parameters, such as vibration, displacement, velocity, air-gap, temperature and other parameters in all operating conditions (in all operating cases including normal and special modes). Figure 6 shows an example of a shaft-vibration signal for a complex vertical-type rotating machine. Figure 7 shows an example of gear unit vibration monitoring. Figure 8 shows an example of the device arrangement used to monitor rotational speed.

Machine troubleshooting

Troubleshooting efforts aim to discover and eliminate the root causes of problems. Too often, in the rush to define what the problem is, sufficient time is not taken to obtain all of the facts, and this thwarts any troubleshooting effort. Any change that has happened recently (or any change compared to design conditions) should be properly identified for all components in rotating machine systems. All functions of the components and sub-systems should be clearly identified. It is necessary to interview all groups, such as operators, maintenance people, manufacturers, sub-vendors and related contractors, during any troubleshooting exercise.

Failed components should be carefully observed and the mode of failure should be identified. The vendor's opinion and any consultant advice should be considered. The machine history should be properly investigated, including both the operating life before failure and the history of any previous failures.

As noted earlier, baseline conditions need to be obtained or established. Operator's logs and reliability data should be examined. Special attention is required when monitored parameters exceed normal values. Trends must be analyzed.

Data related to the failed component's supply source (that is, the manufacturer or other supplier), design, materials, manufacturing details, assembly data and tolerances should all be considered. Unit piping, piping stress analysis, thermal loads, nozzle loads, temperatures, support conditions, foundation and generally all surrounding facilities should also be analyzed during the investigation to ascertain the root cause of a component failure.

New modeling methods, advanced simulation techniques and numerical calculations have become important tools in modern troubleshooting and failure root-cause analysis. For example, rubbing on the casing is a widely reported problem in rotating components. Realistic simulations of the dynamic and thermal expansion of rotating parts and inner casings are required to carry out a root-cause analysis in such cases. For many reliability studies or troubleshooting exercises, the use of accurate finite element analysis (FEA) of the machine can also yield important insight. Figure 9 shows an example of an FEM model with fine meshing carried out for a fan impeller.

Notes on gear unit inspection

A broken gear tooth is one of the most serious problems that can occur in a gear unit. Because of the relative weakness of the softer core material of gears, any gear tooth that has substantial surface deterioration may be at risk of breakage.

The most common surface damage mechanism is pitting. Gear pitting occurs as the result of a combination of fatigue forces and surface tension. Any pits on the surface of a gear are cause for concern because they show that the tooth loads are far in excess of the design loads or there is a problem. Pitting could also indicate serious misalignment, contact pattern issues or metallurgical problems.

Poor tooth contact, eccentric loading that causes pitting, and the resultant tooth fractures are the most frequently experienced gear problems. Micro-pitting, a less severe form of surface fatigue damage, sometimes occurs when there is an inadequate lubricant film. It shows up where the high spots of the mating gear surfaces create pressures sufficient to cause a series of tiny fatigue spalls (resulting in a sandblasted appearance).

The normal progression of damage in a tooth with excessive loads (or misalignment) is that the micro-pitting eventually yields to full-scale pitting. If the micro-pitting occurs in bands and is uniform and well distributed, it indicates that the gears are heavily loaded or there were some machining errors. When micro-pitting is off to one side of a gear, it indicates there is excessive misalignment within the unit; this increases the chance of catastrophic failure. Future up-rating or modifications (particularly speed changes) may be required for some gear-unit-driven rotating-machine trains.

FIGURE 6. Shown here is an example of shaft vibration monitoring on a complex vertical-type rotating machine. The radial vibration amplitude of the shaft is an indicator of the overall mechanical condition. Such a vibration signature allows operators to detect many machine malfunctions, including rotor unbalance, misalignment, bearing wear and rubs. In some complex rotating machines, vibrations are not easily detected by measuring the dynamic motion of the shaft relative to that of the bearing. Depending on bearing stiffness, vibrations may be transmitted entirely to the bearing housings. Such a vibration signature often cannot be detected by conventional methods for measuring shaft vibration. In such cases, a piezoelectric accelerometer or seismic velocity-meter may be used to measure the absolute severity of the bearing vibration

FIGURE 7. Continuous (online) vibration monitoring should be implemented for critical gear units. The dynamic forces and vibration that result from gear meshing often present challenges to unit reliability, causing excessive gear and bearing wear and adversely affect the driver, driven equipment, steel structures, foundation and even nearby equipment

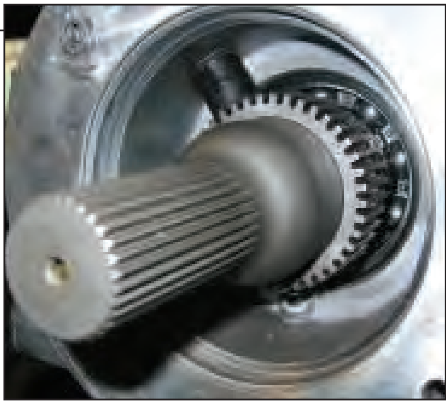

FIGURE 8. Shown here is an example of a rotational-speed-monitoring system using gear teeth. Common sensors that are used to monitor rotating speed and the phase angle of the rotor are known as rotational-speed sensors or phase-angle-reference transducers (most often called key-phasor transducers). This type of sensor can be used to tie the rotor vibration data (or other performance or monitoring data) to the shaft rotational motion or phase angle reference. The resulting information is extremely valuable for balancing, vibration condition monitoring, torsional monitoring and diagnosing various machine malfunctions

The gear unit could be designed to allow for a replacement gear set with a different speed ratio, thereby providing the required operating speed for the alternate operating cases.

Practical recommendations

Establishing proper alarm and trip setpoints is very important for proper operation of a CPI rotating machine. These setpoints should be properly selected to avoid unnecessary alarms or shutdowns (trips). Malfunctions and problems must be identified in the early stages to avoid catastrophic damages. While appropriate setpoints must be selected on a case-by-case basis, the following rules of thumb and practical recommendations generally apply.

Regarding rolling-element bearings, peak housing vibration and temperatures in the bearing housing should be maintained below around 12 mm/s and 90°C, respectively. For hydrodynamic bearings, peak-to-peak housing vibration and temperature in the bearing housing are recommended to be maintained below around 70 microns and 115°C, respectively. For rolling-element and hydrodynamic thrust bearings, as a rough indication, axial displacement should be maintained below around 1.2 mm/s and 0.6 mm, respectively. Lubrication-oil supply and return temperatures should be maintained below around 55°C and 85°C, respectively.

Lubrication oil analysis is another effective tool for evaluating bearing health. It is helpful to measure the temperature variation (typically using a thermographic method), both across the gear teeth and around the gear sets, to get an idea of the loading and misalignment in the gear unit. The maximum variation should not exceed a certain limit (most often in 6–10°C range).

As a rule of thumb for dynamic machines, if for a given flowrate and shaft speed the head produced falls below the value predicted (based on a certified and tested head-flowrate characteristic curve) by greater than 10–15%, the dynamic machine may be in peril and should be inspected at the first opportunity.

Case study

This case study is presented for a large instrument-air compressor. It supplies instrument air to an air receiver, which delivers instrument air for various continuous and intermittent end uses. The compressor train is started and stopped by the pressure of the air receiver.

The machine uses sleeve-type bearings and has suffered from bearing failure. During an inspection after the failure, the bearings were found to be totally black; and the Babbitt — a special material or alloys that is used for the bearing surface to provide a thin surface layer in a complex, multi-metal structure and help to resist galling — was not found on bearing shells.

FIGURE 9. Finite element modeling (FEM) model with fine meshing for a fan impeller helps to identify stresses, strains and displacements in the fan impeller

An investigation showed that the plant's consumption of instrument air had increased four times compared to its design value. Since the flow produced by the compressor remained unchanged, the increased flow of instrument air reduced the pressure in the air receiver more rapidly, and thus resulted in more-frequent stops and starts of the machine. This put the bearings under more-transient stresses, resulting in a longer duration of excessive load and a corresponding, transient lack of lubrication.

In this case, the compressor vendor confirmed that this compressor model was originally designed for continuous operation. While the unit can be operated in long durations of intermittent operation — as proposed for the specified condition during the bidding stage — it cannot afford four times the usual number of starts and stops.

The proposed solution for this case is to change the compressor-control philosophy by eliminating stop/start operation, and operating the compressor continuously, using a bypass control valve instead to maintain the desired air-receiver pressure. In other words, the compressor was switched to continuous operation and a new recycle loop, from the compressor discharge to the compressor suction, was provided to decrease the discharge pressure. The discharge pressure needed to be decreased to relieve stored instrument air in the air receiver from the discharge to the suction. With this new mode of operation, there is no need to stop the compressor. The valve at the recycle (or bypass) loop is opened, as needed, to adjust the instrument air flowrate. ■

Edited by Suzanne Shelley

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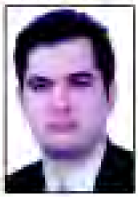

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Show Preview

INTERPHEX 2012
Conference & Exhibition

Freeman Technology

Arizona Instruments

The Interphex 2012 conference and exhibition, which will bring together a wide range of professionals and companies in the arena of pharmaceutical production equipment and services, takes place May 1–3 at the Jacob Javits Convention Center in New York. The tradeshow features over 650 exhibitors showing more than 1,000 product lines in every category in the drug and device manufacturing industry.

The event will also include more than 30 technical sessions in a five-track conference program. More than 50 industry and government speakers will present on a variety of topics in the following tracks: product development; facility and process design; manufacturing and packaging; regulatory quality control and quality assurance; and supply chain.

Within the product-development track, presentation topics will include mitigating microbial risk and process analytical technology (PAT), while the facility and process design track features case studies on modular construction, water reuse and asset optimization. Single-use technologies and cleaning validation are among the topics highlighted in the manufacturing and packaging track presentations.

Conference keynote speakers include industry leaders and government officials. In one keynote address, Jim Miller, president of PharmSource Information Services Inc. will discuss the state of the outsourcing industry. Jeffrey Baker, deputy director of the Office of Biotechnology Products within the U.S. Food and Drug Administration (FDA), will outline the elements of a reliable drug supply in another. The third keynote will be delivered by Richard Smith, director of life sciences and specialty services at FedEx. Smith will cover considerations for maintaining product temperatures during shipping and delivery.

The event's exhibit floor will be open from 10:00 a.m. to 5:00 p.m. May 1 and 2, and from 10:00 a.m. to 3:00 p.m. on May 3. The following descriptions represent a small sample of the products and services that will be featured on the exhibit floor during the show:

This moisture analyzer has a four-decimal-place balance

The Computrac MAX 4000XL (photo) is a moisture-in-solids analyzer that features a four-decimal-place analytical balance, as well as a nickel-chromium heating element, and production-durable steel casing. The instrument, which can handle sample sizes from 100 mg to 40 g, has fan-assisted cooldown, a color LCD display, and is compliant with 21 CFR Part 11 U.S. Federal regulations. It is designed with both USB and Ethernet ports. Booth 2976 — *Arizona Instruments LLC, Chandler, Ariz.*
www.azic.com

Measure powder properties with this device

The FT4 Powder Rheometer (photo) can carry out several bulk property tests for powders, including those for density, compressibility and permeability, allowing users to quantify powder properties in terms of flow and processability. Using a patented measurement methodology and fully automated shear cell, the FT4 generates information that can help improve process design and support effective troubleshooting and optimization of powder handling operations, the company says. The instrument is available with a new version of powder rheometer software that features an intuitive graphical interface, and displays realtime test information. It also includes step-by-step guidance to help new users select and run tests. Booth 2136 — *Freeman Technology Ltd., Tewkesbury, U.K.*
www.freemantech.co.uk

Note: For more information, circle the 3-digit number on p. 70, or use the website designation.

Show Preview

Filamatic

This actuator has 360-deg rotation capability

The S360 range of actuators (photo, p. 61) are designed for life-science-related applications. Featuring a modular range, this compact, lightweight, piston-type pneumatic actuator delivers optimum dimensional envelope and closure performance. Its full 360-deg rotation capability allows for flexible installation and air-port alignment, and its smooth corrosion-resistant profile optimizes cleanability. The S360 is appropriate for sterile biopharmaceutical applications including clean utilities, fermentation and downstream processing. Booth 3320 — *Crane ChemPharma Flow Solutions, Cincinnati, Ohio*

www.cranechempharma.com

This fabric door has a soft bottom edge

The Iso-Roll fabric roll-up door is designed for material-transfer airlocks, equipment washrooms and packaging and staging areas. The bottom edge of the door is soft, and the curtain molds to the contours of the floor to provide optimal sealing. The Iso-Roll has sloped shrouds that completely enclose the curtain roll and drive motor. For manual release in the event of emergency egress, no special release mechanism is required. The door has adjustable open and close speeds and automatically resets after impact. Booth 1536 — *Cleanseal Door Systems, Milwaukee, Wisc.*

www.cleansealdoors.com

Accommodate four pumps with this compact filler

Adaptafil (photo) is a versatile, semi-automatic benchtop filler with a touchscreen human-machine interface. It has the ability to accommodate four pumps (piston, peristaltic, gear and lobe) on one base, allowing the user to change the pump depending on the application, the company says. The multiple pump options make this machine ideal for filling volumes in the range of milliliters to gallons and product viscosities that range from aqueous to viscous. The benchtop filler has a compact footprint, but still offers capabilities typically seen on automatic equipment. These capabilities include saving and copying recipes, data transfer and servo-driven technology. Booth 2828 — *Filamatic, Baltimore, Md.*

www.filamatic.com ■

Scott Jenkins

MARCH
New Products

Henkel

NovaTorque

Rockwell Automation

Safely Sampling

Achieve high efficiencies with these permanent-magnet motors

PremiumPlus motors are brushless permanent-magnet motors (photo) that are driven by variable-frequency drives (VFDs). Available in 3-hp and 5-hp sizes, the motors achieve motor-only rated point efficiencies of 93% and 92% for the two sizes, respectively, the company says. The motors have a unique flux-focusing stator and rotor-hub geometry that allow them to achieve high performance with ferrite-based permanent magnets, rather than those requiring costly rare-earth metals, such as neodymium. Because they use ferrite magnets, the motors are priced comparably to induction motors, the company says. PremiumPlus motors are packaged in standard NEMA frame sizes and mounting dimensions for easy substitution. The motors are compatible with VFDs from most leading manufacturers. — *NovaTorque Inc., Sunnyvale, Calif.*
www.novatorque.com

Track energy usage with these monitors

With these two energy-use monitors, companies can gain insight into how, when and where energy is being expended throughout a production process. The PowerMonitor W 250 (photo) features a self-generating wireless communications platform that is ideally suited to applications located in areas where hard-wired networking is cost-prohibitive. The wireless W250 power meter can measure energy consumption at multiple metering locations, including remote or confined spaces. The PowerMonitor 500 power meter can be used for smaller-consumption and demand-monitoring applications. It features an on-device LCD display in a small, panel-mounted footprint. Operators can access realtime energy demand and consumption data at the machine or process level. — *Rockwell Automation Inc., Milwaukee, Wisc.*
www.rockwellautomation.com

Sample corrosive or toxic process fluids with this device

The LSS-30-PP (photo) is a sampling system designed to allow sampling of hazardous process fluids without personnel contact. The LSS-30-PP is similar in design to the LSS-140-ST from this company, but has a smaller sample cylinder (300 mL), and has wetted parts constructed from polypropylene for situations where non-metallic material must be used for product-wetted parts. Like its larger cousin, the LSS-30-PP has two flanged connections for integration with the sample piping, and a back-mounted bracket to enable easy installation on a column stand or existing column steel. The unit has a top feed valve and a bottom discharge valve that can be opened to allow product to flow through the sampling station. When a representative product flow is established, the bottom discharge valve can be closed, and the sample cylinder fills to a desired height. The top feed valve is then closed, and the sample cylinder can be removed for analysis or observation. The product is completely isolated from physical contact with plant workers. — *Safely Sampling, Aurora, Ill.*
www.safelysampling.com

Prevent wear and cavitation with this coating

Loctite Nordbak 7255 Sprayable Ceramic Coating is a two-part ceramic coating designed to protect metal surfaces of industrial equipment from wear, abrasion and corrosion. The product is packaged in a convenient, reusable, dual-cartridge dispenser (photo) and is sprayed onto metal components to create smooth, low-friction surfaces

Note: For more information, circle the 3-digit number on p. 70, or use the website designation.

that improve equipment efficiency. The sprayable coating is designed to be quickly and evenly applied to large surfaces as well as complex or intricate areas that are difficult to coat. The 7355 Coating is ideal for tank linings, mixing vessels, pump housings, impellers, chutes, troughs and centrifuge components. The ceramic coating adheres well to a variety of metal surface types and acts as a sacrificial and renewable surface. It can be reapplied over existing epoxy surfaces, the company says. — *Henkel NA, Rocky Hill, Conn.*
www.henkelna.com

A brighter LED is a feature of this leak-detection kit

The OPK-340 Industrial Leak Detection Kit (photo) features a blue-light LED leak-detection flashlight that is 15 times brighter than standard LED lights, says the company. The super-high-intensity light is powered by a rechargeable nickel-metal-hydride battery and has a life of 50,000 h, and an inspection range of up to 20 ft. Within the kit, the cordless inspection light is accompanied by a container of concentrated fluorescent water dye that can be used for finding leaks in water-based systems. The OPK-340 also comes with a dye cleaner and a.c. and d.c. chargers for the light. The kit is suitable for leak detection in hydraulic equipment, compressors, engines, gearboxes, fuel systems and water-based systems. — *Spectronics Corp., Westbury, N.Y.*
www.spectroline.com

Optimized features for this screener

This company has recently optimized product features for its Mogensen particle sizer. The Mogensen sizer has sloped screen decks to allow particles to have freedom of movement while maximizing the capacity of screen area. For example, the output ports have been redesigned for improved material flow, the vibration system provides increased capacity and the screen tensioning system has been made more accurate. The simplified tensioning system also reduces maintenance requirements. In addition, redesigned dust covers are more ergonomically sound and scratch resistant. — *Almo Process Technology, Cincinnati, Ohio*
www.almoprocess.com ■

Scott Jenkins

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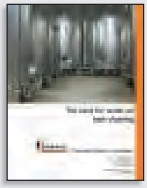

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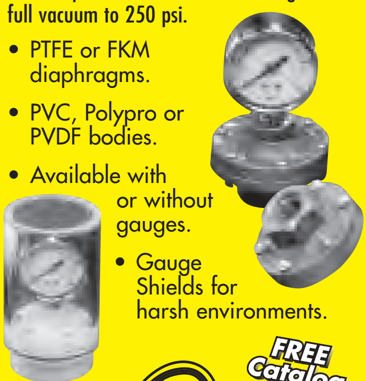

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BUSINESS NEWS

PLANT WATCH

AkzoNobel invests €80 million to supply new Suzano pulp mill in Brazil

February 1, 2012 — AkzoNobel (Amsterdam, the Netherlands; www.akzonobel.com) plans to invest €80 million in the construction of a new pulp "chemical island" facility in Brazil. The plant, operated by the company's Pulp and Paper Chemicals business, Eka Chemicals, will supply the Suzano Maranhão pulp mill. The investment will involve supplying, storing and handling all chemicals for the 1.5-million-ton/yr pulp mill, which is being constructed in Imperatriz, Maranhão, Brazil. The mill is expected to come on stream in the 4th Q of 2013.

Toyo awarded contract for caprolactam plant in China

January 22, 2012 — Toyo Engineering Corp. (Toyo; Chiba, Japan; www.toyo-eng.co.jp) has been awarded a contract for a caprolactam plant for DSM Nanjing Chemical Co., which is a joint venture (JV) between Royal DSM N.V. and Sinopec Group. The project aims to install a 200,000-ton/yr caprolactam plant in Nanjing, China, which is in addition to an existing 200,000 ton/yr caprolactam plant. The project involves an investment of approximately $300 million, and is scheduled to be completed in the 3rd Q of 2013.

BASF to build an integrated TDI plant in Ludwigshafen

January 17, 2012 — BASF SE (Ludwigshafen, Germany; www.basf.com) says it will build a single-train 300,000-m.t./yr production plant for toluene diisocyanate (TDI) and expand additional plants for its precursors at its site in Ludwigshafen. These include the construction of a new hydrogen-chloride recycling plant as well as the expansion of plants for nitric acid, chlorine and synthesis gas. It also plans to expand the aromatics complex at the site for the supply of toluene. Total investment including the required infrastructure will be about €1 billion. Production will start at the end of 2014. BASF plans to close its 80,000-m.t./yr TDI plant in Schwarzheide, Germany, when the new plant goes onstream.

Toyo awarded contract for a bioethanol production facility in Malaysia

January 17, 2012 — Toyo Engineering & Construction Sdn. Bhd. (Toyo-Malaysia), a Malaysian subsidiary of Toyo Engineering Corp. has been awarded a contract by a JV company between GlycosBio Asia Sdn. Bhd. and Malaysian Bio-XCell Sdn. Bhd., to build a bioethanol production facility with a capability of 10,000 ton/yr. GlycosBio Asia Sdn. Bhd. is a subsidiary of Glycos Biotechnologies Inc. (Houston; www.glycosbio.com). Bio-XCell Sdn. Bhd. owns and develops a government-supported biotechnology industrial park in Malaysia. This plant is to produce industrial-grade bioethanol from crude glycerin. The project is scheduled for completion in the 2nd Q of 2013. The plant will be developed in several phases with a total planned production capacity of up to 30,000 ton/yr by 2014.

MERGERS AND ACQUISITIONS

Dover's Pump Solutions Group to acquire the Maag Group

February 13, 2012 – Pump Solutions Group (PSG; Downer's Grove, Ill.; www.pumpsg.com), a business unit within the Engineered Systems segment of Dover Corp., has signed a definitive agreement to acquire the Maag Group headquartered in Zurich, Switzerland. The Maag Group, which posted a 2011 revenue of approximately $170 million, will operate as a business unit within PSG. The transaction is subject to customary regulatory approvals, and is expected to close around the end of the 1st Q of 2012. Terms of the transaction were not disclosed.

Eastman Chemical Co. plans to acquire Solutia Inc.

January 27, 2012 — Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) and Solutia Inc. (St. Louis, Mo.; www.solutia.com) have entered into a definitive agreement, under which Eastman will acquire Solutia. Under the terms of the agreement, Solutia stockholders will receive $22 in cash and 0.12 shares of Eastman common stock for each share of Solutia common stock. This represents a total transaction value of approximately $4.7 billion, including the assumption of Solutia's debt. The transaction, which is expected to close in mid-2012, was approved by the boards of directors of both companies. It remains subject to approval by Solutia's shareholders and receipt of required regulatory approvals and other closing conditions.

Siemens to acquire Cambridge Water Technology

January 25, 2012 — Siemens Industry Automation Division (Warrendale, Pa.; www.siemens.com/industryautomation) has entered into an agreement to acquire Cambridge Water Technology (Cambridge, Mass.; www.cambridgewatertech.com), which is expected to be combined with Siemens' municipal wastewater business and will continue to operate out of Cambridge, Mass. The planned acquisition will include global technology rights, but not Cambridge Water Technology's subsidiaries outside of the U.S.

Rhodia and Avantium to jointly develop bio-based polyamides

January 24, 2012 — Rhodia (Paris, France; www.rhodia.com), a member of the Solvay Group, and Avantium (Amsterdam, the Netherlands; www.avantium.com) have entered into a partnership to jointly develop a range of new bio-based polyamides. This partnership expands and completes the previously announced development agreement in the field of bio-based engineering plastics between Solvay and Avantium. In the frame of this joint development, the companies will explore the market potential of polyamide compositions on the basis of YXY building blocks (YXY is Avantium's brand name of a family of "green" building blocks. For more on this and other bio-based materials, see The Bio-Based Economy, *Chem. Eng.*, August, 2011, pp. 14–16). Rhodia and Avantium have entered into a multi-year, exclusive collaboration toward commercialization of these new polyamides.

Solvay creates new business unit to focus on energy and carbon dioxide

January 23, 2012 — Solvay (Brussels, Belgium; www.solvay.com) has announced the creation of Solvay Energy Services, the first concrete outcome of the integration of Solvay and Rhodia. This new business aims to optimize the energy costs and CO_2 emissions both of the Group and on behalf of third parties. The business will also develop activities to help customers reduce their environmental footprint. These will focus on energy services, CO_2 management and renewable energy and biofuels.

U.K.- and U.S.-based biobutanol manufacturers merge

January 20, 2012 — Green Biologics Ltd. (GBL; Abingdon, Oxfordshire, U.K.; www.greenbiologics.com), an industrial biotechnology company has merged with Butylfuel Inc., a U.S.-based renewable chemicals and biofuels company. The new company will operate under the Green Biologics name and will continue to be headquartered in Abingdon, U.K. with a strong operational presence and commercial focus in the U.S. by Butylfuel Inc., which will become Green Biologics, Inc. The merged GBL will be a globally managed company focused on the production of C4 chemicals and advanced fuels from renewable feedstocks. ■

Dorothy Lozowski

FOR ADDITIONAL NEWS AS IT DEVELOPS, PLEASE VISIT WWW.CHE.COM

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FOR MORE ECONOMIC INDICATORS, SEE NEXT PAGE

Economic Indicators

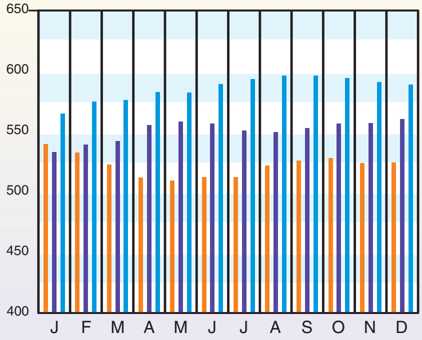
2009 2010 2011 2012

DOWNLOAD THE *CEPCI* TWO WEEKS SOONER AT *WWW.CHE.COM/PCI*

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Dec.'11 Prelim.	Nov.'11 Final	Dec.'10 Final
***CE* Index**	588.8	590.8	560.3
Equipment	718.6	721.0	674.6
Heat exchangers & tanks	681.5	686.7	627.1
Process machinery	670.9	674.1	627.6
Pipe, valves & fittings	902.1	899.3	854.3
Process instruments	427.4	428.0	426.2
Pumps & compressors	910.1	910.4	903.6
Electrical equipment	511.5	510.6	488.4
Structural supports & misc	762.4	767.5	696.3
Construction labor	324.5	326.6	328.1
Buildings	519.1	519.0	503.3
Engineering & supervision	329.6	330.4	335.6

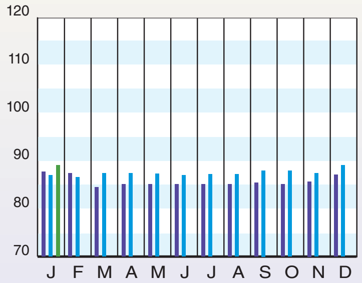
Annual Index:
2003 = 402.0
2004 = 444.2
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8



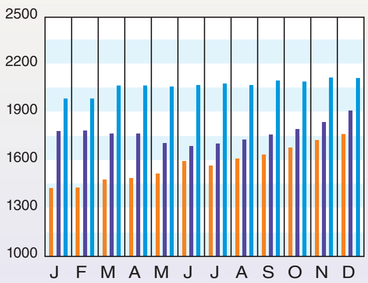
CURRENT BUSINESS INDICATORS

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2007 = 100)	Jan.'12	=	89.1	Dec.'11	=	89.1	Nov.'11	=	87.4	Jan.'11	=	87.0
CPI value of output, $ billions	Dec.'11	=	2,117.1	Nov.'11	=	2,121.0	Oct.'11	=	2,095.8	Dec.'10	=	1,914.6
CPI operating rate, %	Jan.'12	=	77.1	Dec.'11	=	77.1	Nov.'11	=	75.6	Jan.'11	=	74.9
Producer prices, industrial chemicals (1982 = 100)	Jan.'12	=	303.9	Dec.'11	=	309.6	Nov.'11	=	320.2	Jan.'11	=	297.4
Industrial Production in Manufacturing (2007=100)	Jan.'12	=	93.5	Dec.'11	=	92.8	Nov.'11	=	91.4	Jan.'11	=	89.4
Hourly earnings index, chemical & allied products (1992 = 100)	Jan.'12	=	165.5	Dec.'11	=	165.5	Nov.'11	=	155.7	Jan.'11	=	156.1
Productivity index, chemicals & allied products (1992 = 100)	Jan.'12	=	108.7	Dec.'11	=	109.8	Nov.'11	=	109.2	Jan.'11	=	112.7

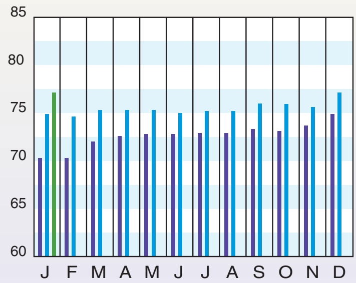
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



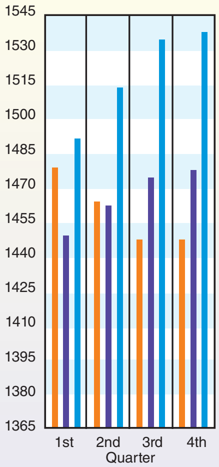
Current Business Indicators provided by IHS Global Insight, Inc., Lexington, Mass.

MARSHALL & SWIFT EQUIPMENT COST INDEX

(1926 = 100)	4th Q 2011	3rd Q 2011	2nd Q 2011	1st Q 2011	4th Q 2010
M & S INDEX	1,536.5	1,533.3	1,512.5	1,490.2	1,476.7
Process industries, average	1,597.7	1,592.5	1,569.0	1,549.8	1,537.0
Cement	1,596.7	1,589.3	1,568.0	1,546.6	1,532.5
Chemicals	1,565.0	1,559.8	1,537.4	1,519.8	1,507.3
Clay products	1,583.6	1,579.2	1,557.5	1,534.9	1,521.4
Glass	1,495.7	1,491.1	1,469.2	1,447.2	1,432.7
Paint	1,613.6	1,608.7	1,584.1	1,560.7	1,545.8
Paper	1,507.6	1,502.4	1,480.7	1,459.4	1,447.6
Petroleum products	1,704.9	1,698.7	1,672.0	1,652.5	1,640.4
Rubber	1,644.2	1,641.4	1,617.4	1,596.2	1,581.5
Related industries					
Electrical power	1,515.0	1,517.6	1,494.9	1,461.2	1,434.9
Mining, milling	1,659.6	1,648.6	1,623.5	1,599.7	1,579.4
Refrigeration	1,889.4	1,884.4	1,856.4	1,827.8	1,809.3
Steam power	1,574.3	1,572.2	1,546.5	1,523.0	1,506.4

Annual Index:

2003 = 1,123.6	2004 = 1,178.5	2005 = 1,244.5	2006 = 1,302.3
2007 = 1,373.3	2008 = 1,449.3	2009 = 1,468.6	2010 = 1,457.4



CURRENT TRENDS

Capital equipment prices, as reflected in the *CE* Plant Cost Index (CEPCI), decreased 0.34% from November to December. Decreases are typical during the third quarter. Annual CEPCI data will be released in next month's issue, when the December 2011 numbers are finalized.

Meanwhile, the CPI Operating Rate, as reported from IHS Global Insight, remained flat from December to January.

Visit www.che.com/pci for more information and other tips on capital cost trends and methodology. ■