CHEMICAL ENGINEERING

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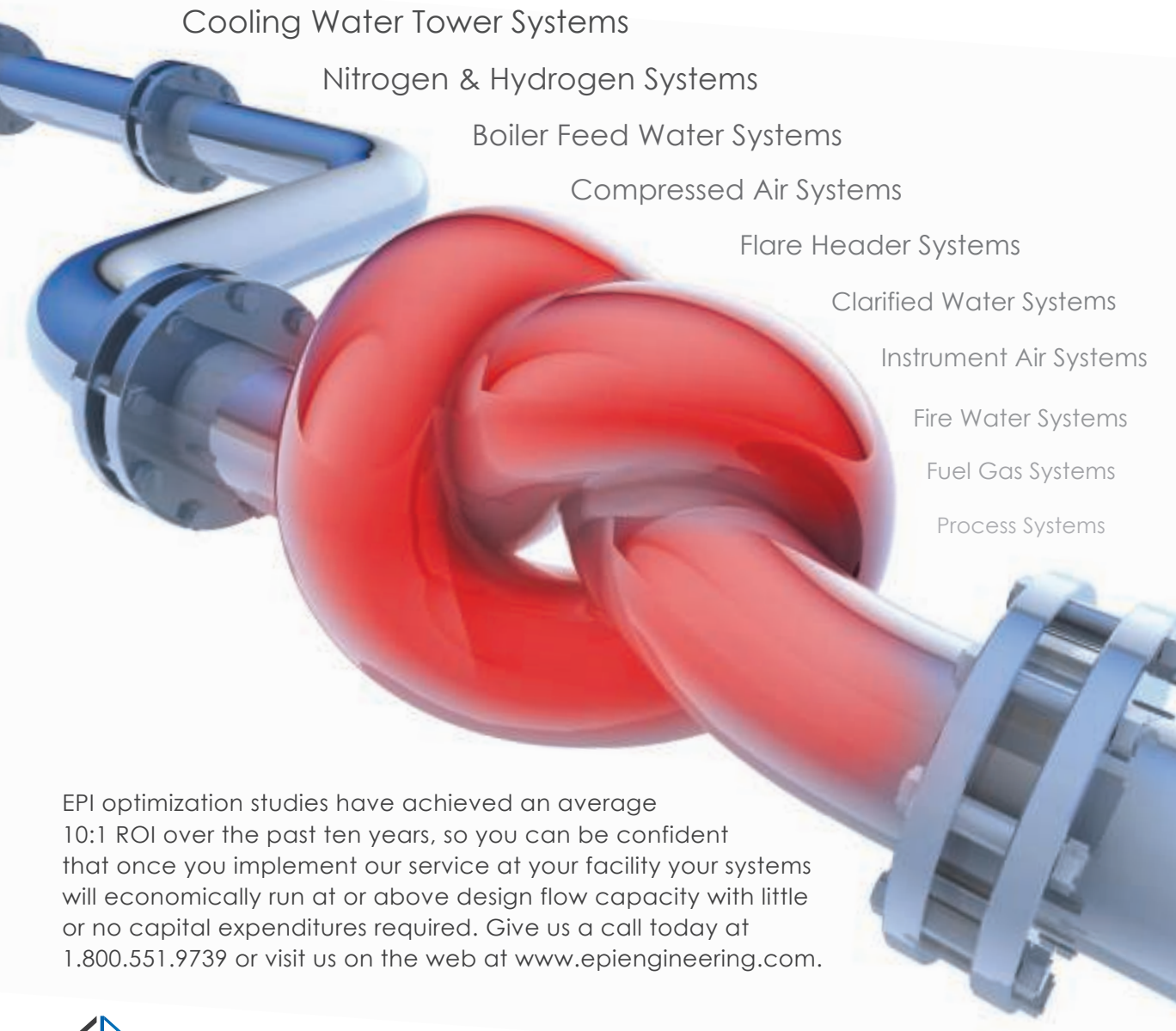

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BPA WORLDWIDE

Editor's Page

Is your control system vulnerable to an attack?

Control and automation in the chemical process industries (CPI) have evolved by leaps and bounds over the past century, bringing along a host of benefits. As a result, today's state-of-the-art facilities are more in line with business objectives, less prone to unplanned shutdowns and better able to manage process safety. However, these improvements come hand-in-hand with a relatively new challenge for which few plant personnel have any expertise. That challenge is control-system security, and it must be addressed alongside nearly every one of the convenient features that the CPI employ.

Consider, for instance, the case of remote access to industrial control systems (ICS). A new report published by the Security Incidents Organization (www.securityincidents.org) shines a light on this practice across the industrial sector. According to data in the organization's Repository for Industrial Security Incidents (RISI) database, up to 65% of industrial facilities allow remote access to their control systems. The benefits of providing realtime system visibility to approved viewers are obvious, but according to the report, approximately 35% of ICS security incidents (from 2001 through 2011) were initiated through remote access. Alarming as those data might be, the report suggests that industry is not necessarily in the dark on this issue. The percentage of control-system security incidents caused by malware (malicious software code) — while still very high at 28% — has been steadily declining over the past five years. In fact, survey data indicate that more than 60% of facilities have implemented patch and anti-malware management programs.

Unfortunately, implementing security protection is neither as simple nor straightforward as the word "patch" might imply. Earlier this year, Industrial Defender (Foxborough, Mass.; www.industrialdefender.com), in conjunction with Pike Research, released Convergence in Automation Systems Protection, a report that helps spell out why control-system security is so daunting today. Growing control-system complexity, is one of the key reasons. The report points out that since most automation environments were developed over decades without a master plan, they now contain heterogeneous systems that are difficult to manage. On top of all that, the exponential growth of intelligent devices deployed in automation systems has definitely not made things simpler. Meanwhile, today's resource constraints require plant managers, engineers and operators to do more with less. As a result, the report says, automation systems now need the same levels of management and security that have been seen in enterprise networks for the past two decades.

Two upcoming events provide opportunities to learn more about these challenges and the ways that experts are addressing them. The Industrial Control Systems Joint Working Group (ICSJWG) 2012 Spring Conference, which is organized by the U.S. Dept. of Homeland Security's (DHS) Control Systems Security Program (CSSP), takes place early this month (May 7–10) in Savannah, Ga. (www.us-cert.gov/control_systems/icsjwg/conference.html). An eight-hour Introduction to Control Systems Cybersecurity training course will also be offered on Thursday, May 10, 2012, at the conference site. Then, later this summer, DHS and the Society of Chemical Manufacturers and Affiliates (SOCMA Washington, D.C.; www.socma.com/events) co-host the 6th Annual Chemical Sector Security Summit & Expo in Baltimore, Md. (July 30–August 1).

In the meantime, consider looking back to Cybersecurity for Chemical Engineers (*CE*, June 2011, pp. 49–53). ■

Rebekkah Marshall

Letters

ChemInnovations Call For Papers

Presentation abstract submission for the 3rd Annual ChemInnovations 2012 Conference & Exhibition, presented by *Chemical Engineering,* is now open. The advisory committee is looking for solutions-based presentations that bridge the knowledge gap through training and technologies. Programming will be separated into a primer level, an intermediate level and an innovative technologies category.

CPI challenges, primer/entry level:

- PLCs — overview of concepts and models
- Process Controls — PLC vs. DCS
- Cost estimation — inside and outside the U.S.
- Fundamentals not covered thoroughly in curriculum
- Process safety
- Technical and report writing
- Risk management
- Business and economics
- Project management
- Optimization, troubleshooting and debottlenecking

CPI challenges, intermediate/management level:

- Mentoring and knowledge transfer
- Improving reliability
- Designing for safety and security
- Asset management
- Improving efficiency and energy use
- DCS, control system upgrading
- Computerized maintenance management and predictive maintenance
- Increasing capacity
- Capital cost estimation
- Risk evaluation and management

Related equipment and services:

- Process equipment
- Liquid, gas and air handling equipment, especially pumps, valves and compressors
- Heat transfer and high energy demand equipment
- Automation and control equipment and software
- Water treatment and reuse strategies, including those that specifically relate to hydraulic fracturing
- Air pollution control and monitoring equipment

For questions about abstract submissions contact Cassie Davie, +1-713-343-1891, cassied@tradefairgroup.com.

Postscripts, corrections

February 2012 (pp. 24–29): In the article, Effective Thermal Design of Cooling Towers, there were mistakes in the print version of Equations (4) and (6). The correct equations are as follows:

$$p_{ws} = \frac{\exp\left[C_1 T^{-1} + C_2 + C_3 T + C_4 T^2 + C_5 T^3 + C_6 \ln(T)\right]}{1{,}000} \quad (4)$$

$$p_w = p_{ws} - \left\{ \frac{1.8 \times (p - p_{ws}) \times (t_{db} - t_{wb})}{\left[2{,}800 - 1.3 \times (1.8 t_{db} + 32)\right]} \right\} \quad (6)$$

These typos do not affect any of the numbers in the Tables or the example problem because the correct equations (not those printed) were used for the calculations. The corrected, online version of the article can be found at www.che.com.

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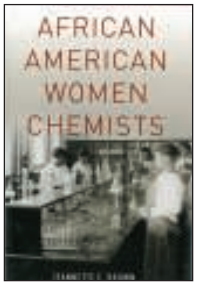


Breaking into the Lab: Engineering Progress for Women in Science. By Sue V. Rosser. New York University Press. Washington Square, New York, NY 10003. Web: nyupress.org. 2012. 249 pages. $35.00.

African American Women Chemists. By Jeannette Brown. Oxford University Press Inc., 198 Madison Ave., New York, NY 100016 Web: oup.com. 2011. 264 pages. $35.00.

Reviewed by Lacey Baggett,
PX2 TAR Superintendent,
BP Corp., Houston

The challenges faced by female scientists and engineers are highlighted in two books with wide-ranging implications for many industries. Jeannette Brown's book follows the careers and lives of African-American women who have left lasting impacts in science, engineering and education since the mid-1800s. Highlighting both professional and personal struggles, the book is equal parts scientific history and inspirational biography. Each narrative shows how — and perhaps more importantly, why — these women were able to overcome seemingly insurmountable challenges to produce lasting contributions.

Sue Rosser's book focuses on the current scarcity of female scientists in senior-level academic positions. This data-driven text explores the issues, and leads to a discussion of the impact of these trends on science, the economy, and on women seeking to pursue science careers. The book culminates in a series of suggestions to help turn the tide.

While the author may limit her potential audience by making broad generalizations about both sexes and leaning to the side of feminism, she is still able to convey her fundamental concepts to a broad population. Detailed studies discussed by the author provide the foundation, leading the reader away from sociological theories and instead focusing on institutional practices that have a greater impact on the development and direction of a female scientist's career. The issues of junior- and senior-level women are contrasted throughout. This technique highlights progress to-date, while focusing on what more can be done to ensure continued improvement — so that the scientific community seizes the opportunity to take advantage of the considerable contributions of professional women scientists and engineers.

Interviews with successful women provide insight into several key areas: career-path opportunities; overcoming common pitfalls of a scientific career; and the pros and cons of a personal and professional life in science. Many issues addressed — including the struggles of creating an acceptable work-life balance — are applicable to all.

One prominent theme in both books is the impact of mentoring — both to help women enter scientific fields, and also to retain and promote them once they pursue science. A key premise for the book appears to be ensuring that mentors understand the experiences encountered

Bookshelf

by women scientists, so they can more effectively guide women during their careers. While the reader may be left with many unresolved questions of how to overcome the challenges in closing the gender gap, the author balances this by suggesting specific, practical behaviors for individuals, as well as providing realistic recommendations for mentors and institutions — all aimed at ensuring that women are valued and properly represented in the future.

Both books highlight the dramatic impact women can have, and are having, on science and engineering. Both encourage women to take ownership of their careers, by providing realistic tips for success and by relating inspiring stories of others. Both books would benefit a wide audience, including young women considering career paths, potential mentors, senior managers seeking to recruit and retain scientific women, and female scientists and engineers.

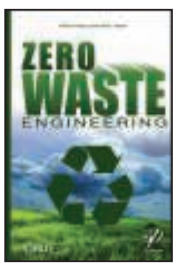
Piping System Fundamentals: A Complete Guide to Gaining a Clear Picture of Fluid Piping Systems. 2nd ed. By Ray Hardee and Jeffrey Sines. ESI Press, 4529 Intelco Loop, SE, Lacey, WA 98503. Web: fluidfundamentals.com. 2012. 160 pages. $95.00.

Petroleum Engineer's Guide to Oil Field Chemicals and Fluids. By Johannes Fink. Elsevier Inc. 30 Corporate Drive, 4th Fl., Burlington, MA 01803. Web: elsevierdirect.com. 2012. 808 pages. $139.95.

Distillation Engineering Handbook: Components and Troubleshooting. By Parthasarathi Chattopadhyay. Tata McGraw-Hill Education Pvt. B-4, Sector 63, Noida, UP 2010301, India. Web: tatamcgrawhill.com. 2011. 1,436 pages. $289.95.

Zero Waste Engineering. By Rafiq Islam. John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030. Web: wiley.net. 2012. 488 pages. $195.00.

Sustainability in the Chemical Industry. By Eric Johnson. Springer Verlag. Heidelberger Platz 3, 14197, Berlin, Germany. Web: springer.com. 2012. 142 pages. $129.00.



Statistical Thermodynamics and Stochastic Kinetics: An Introduction for Engineers. By Yiannis N. Kaznessis. Cambridge University Press, 32 Avenue of the Americas, New York, NY 10013. Web: cambridge.org. 2012. 314 pages. $85.00. ■

Scott Jenkins

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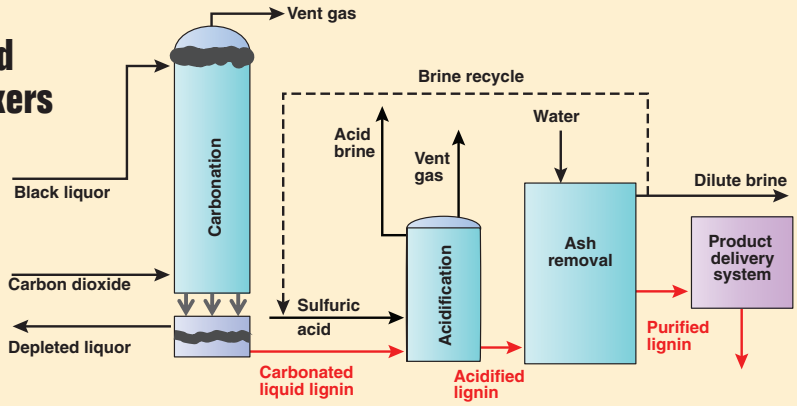
Lignin recovery process could improve profits for papermakers



Recovery boilers, in which pulp and paper companies burn spent black liquor from the kraft pulping process to recover and recycle sodium and sulfur, are a bottleneck in many paper mills. The reason is that they operate at their upper limit of heat flux into the boiler tubes, thus preventing an increase in the mills' output, explains John Blackburn, co-founder of Liquid Lignin Co. (LLC, Charleston, S.C.; www.liquidlignin.com). LLC is developing a process that promises to relieve this situation by removing lignin (a major fuel component) from the liquor. Another benefit is that the lignin, a natural polymer, can be used to replace petroleum-based chemicals such as phenol in wood adhesives — much more valuable applications than boiler fuel, says Blackburn.

The process (flowsheet), called Sequential Liquid-Lignin Recovery and Purification (SLRP), is a continuous, three-stage operation. In the first stage, the black liquor's pH is reduced from 14 to 9 by counter-current contact with carbon dioxide. As the pH drops, lignin precipitates as a dense-phase "liquid lignin" that is phase-separated from the carbonated black liquor. The depleted liquor is recycled to the pulping process and the liquid lignin goes to the second stage, where it reacts with sulfuric acid in an agitated reactor. This reduces the pH to 2, which drives off the remaining sodium ions from the lignin. Finally, the lignin is leached by a counter-current water stream in a packed column to obtain solid, high-purity lignin.

The entire process is conducted at a temperature of more than 100°C at pressures up to 150 psig, says Blackburn. He notes that these conditions retain the heat of reaction and prevent boiling, which would interfere with phase separation. Process heat, beyond the black liquor's initial heat, is generated by the heats of reaction of carbon dioxide and sulfuric acid.

LLC is operating a pilot plant, processing 1 L/min of black liquor, and plans to install a prototype unit in a commercial paper mill early next year. The latter will produce 5–10 ton/d of lignin, says Blackburn. A commercial plant to produce 50,000 ton/yr of lignin would cost roughly $20–30 million, he says, versus more than $200 million to retrofit a recovery boiler.

Iron-based catalyst shows promise for alkene hydrosilylations

A catalyst in which iron atoms are complexed with the ligand pyridine diimine (PDI) has shown promise as a replacement for high-cost platinum-based catalysts for industrial olefin-hydrosilylation reactions.

Developed by the research group of Paul Chirik at Princeton University (www.princeton.edu) and scientists at Momentive Performance Materials, Inc. (Waterford, N.Y.; www.momentive.com), the catalyst allows the selective reaction of tertiary silanes to alkenes in an inert atmosphere under mild conditions. The resulting alkylsilanes have several industrial uses, including silicone fluids for personal-care products and agricultural adjuvants. These catalysts may also find use in catalyzing the crosslinking of silicone release coatings and silicone elastomers.

Two key features of the ligand allow its use in the context of a hydrosilylation catalyst. The PDI ligand offers steric protection of the metal center, explains Keith Weller, Momentive scientist, which allows the catalyst to be highly selective for anti-Markovnikov addition of the silane to the alkene. The second feature is that the ligand, as well as the metal center, can participate electronically in catalyzing the reaction. This allows the two-electron chemistry characteristic of the traditional precious-metal catalysts to dominate over the one-electron redox processes for which first-row transition metals have a propensity.

"The PDI ligand is straightforward to synthesize," Momentive's Weller notes, "and its conversion into the catalyst precursor is simple," so the academic-industrial team is working on developing the catalyst for eventual commercialization.

Double-effect coating

Researchers at the Leibniz-Instutut für Neue Materialien GmbH (INM; Saarbrücken, Germany; www.inm-gmbh.de) have developed a nanocomposite coating that simultaneously protects against corrosion while having lubrication properties similar to grease and oil. The new material is suitable for coating metals (such as steel, Al, Mg) and metal alloys.

To form the composite, the researchers embedded platelet-like solid-state lubricants and platelet-like particles in a binder. When applied onto a surface, a well-arranged microstructure (imbricate structure) forms, explains Carsten Becker-Willinger, head of INM's Nanomere program division. A transfer film forms between the low-friction coating and the counterpart,

(*Continues on p. 12*)

Note: For more information, circle the 3-digit number on p. 61, or use the website designation.

A more sensitive sensor for ions in solution

A research team from the Institute for Photonics and Advanced Sensing, and the School of Chemistry and Physics, the University of Adelaide, South Australia (www.adelaide.edu.au) has combined suspended-core microstructured optical fibers (MOFs) with photoinduced electron transfer (PET) to demonstrate a new type of fluorescent optical fiber-dip sensor for small volume ion detection. Led by professor Tanya Monro, the team's research is expected to lead to optical fiber dip-sensors that combine the advantages of MOFs with the benefits of the fluorescence PET effect for biological, chemical and environmental sensing applications.

Small-core MOFs with relatively large air holes surrounding the core can enable close interaction of liquids loaded into the holes, with a portion of the guided light located in these voids. The liquids can contain optically or chemically active materials (or both) that facilitate interrogation of the species of interest at nano- to micro-liter volume scales.

The PET effect is a well-established tool for fluorescent molecular sensing and successful commercial PET systems have been developed for sodium, potassium, and calcium sensing. However, the Adelaide team believes it is the first to demonstrate a PET-based MOF dip-sensor. It has achieved proof-of-principle through detection of sodium ion solutions down to 18.4 ppm, employing a soft-glass suspended-core optical fiber combined with a synthesized model PET-fluoroionophore system suitable for use in intense, locally concentrated light fields.

According to the team, the sensor's performance indicates strong potential for the development of a cost-effective, flexible and portable sensor platform.

The University of Adelaide team is now working toward improving signal stability, sensitivity and signal-to-noise ratio. It aims to develop an ion-selective version of this dip-sensor, as well as using PET-fluoroionophore surface attachment strategies for aqueous-based sample detection.

(*Continued from p. 11*)

which allows an almost friction-less sliding of the surfaces. The imbricate structure also acts as a barrier, thereby preventing the penetration of humidity or salts to the metal surface, he says.

The low-friction coating can be applied using conventional wet-chemical processes, such as spray- or dip-coating. By a simple thermal curing, the imbricate structure forms in a self-organization without further interference.

Japan-GTL demo

A six-year, Japan-GTL (gas-to-liquids) demonstration test project was successfully completed at the end of March, having achieved all of the R&D goals, and establishing the Japan-GTL process applicable to commercial plants, according to a joint release of the six participating Japanese companies: Inpex Corp., JX Nippon Oil & Energy Corp., Japan Petroleum Exploration Co., Cosmos Oil Co., Nippon Steel Engineering Co. and

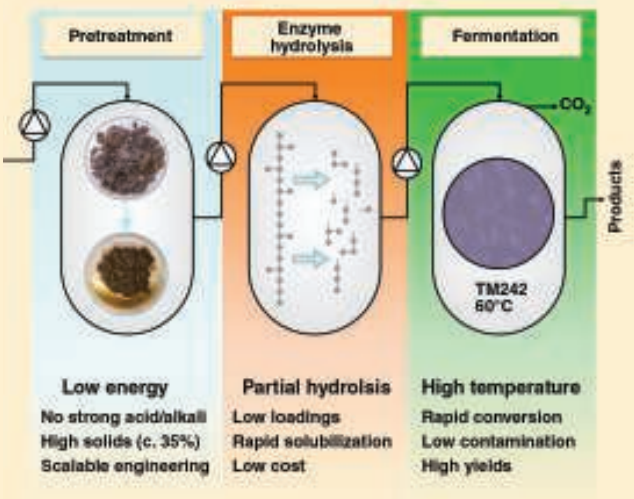
(*Continues on p. 14*)

Municipal solid waste is one feedstock for this bioethanol process

The technology surrounding a hydrolysis- and fermentation-based process that is capable of utilizing municipal solid waste (MSW) and biomass waste to produce cellulosic bioethanol at low cost is now available for licensing from its developer, TMO Renewables Ltd. (Guildford, U.K.; www.tmo-group.com).

Several of the cost-saving measures depend on the capabilities of a heat-loving bacterium that has been developed by TMO to metabolize a wide range of sugars, including oligomeric C5 and C6 sugars into ethanol at high yields.

"Because the organism is so effective at metabolizing a range of sugars, our pretreatment process requires less chemicals, our hydrolysis step requires less enzymes and our fermentation step requires lower residence time," explains Robert Parker, TMO's CEO. The heat-loving bacterium used in the fermentation is the result of a long screening process led by the late Tony Atkinson, a professor who co-founded the company. The company developed and applied a number of proprietary metabolic engineering techniques to create a gene-knockout strain of bacteria that produces ethanol in high amounts.



While the process technology — pre-treatment, hydrolysis, fermentation and distillation — has been extensively used elsewhere, Parker says that TMO engineers have come up with some proprietary advances that integrate the process with the biotechnological characteristics of the organism to yield a robust and low-cost system.

TMO operates a one-million-liter demonstration plant in the U.K., where it works with various client feedstocks, including MSW, cassava stalk waste and others. TMO recently signed licensing deals with companies in Russia, China, Brazil and the U.S.

A new catalyst enables room-temperature interconversion of CO_2 and formic acid

Brookhaven National Laboratory

A new catalyst that converts H_2 and CO_2 into formic acid under mild conditions has been developed by researchers at the Solar Light Energy Conversion Group of Energy Technology Research Institute, National Institute for Advanced Industrial Science and Technology (AIST; Tsukuba, Japan; unit.aist.go.jp/energy/index_e.htm) and Brookhaven National Institute (BNL; Upton, N.Y.; www.bnl.gov). And because the reaction can be reversed by a simple pH change to produce CO-free H_2, the researchers believe the system may someday be used as a safe way to store and transport H_2 for fuel cells.

AIST was the first to develop a catalyst that enables the production of the formic acid through the reaction of H_2 and CO_2 in water under mild conditions, and also succeeded producing CO-free H_2 with the world's highest efficiency by the decomposition of formic acid in water — without organic additives. BNL has technologies on reaction mechanism analysis of artificial photonic synthesis catalyst and proton-relay-based hydrogen activation. By combining the two group's efforts, the researchers developed a highly efficient system based on a homogeneous iridium catalyst with proton-responsive ligands (diagram). With this system, they can produce formic acid ten times faster and with 100-times higher yield compared to existing technology.

The collaborators are now working on the development of a high-purity, hydrogen-production facility based on the continuous decomposition of the formic acid with a combined CO_2 separation unit. AIST is also investigating a highly-efficient artificial photosynthesis system based on a visible-light-response semiconductor catalyst that could produce energy storage materials using water and CO_2.

(*Continued from p. 12*)

Chiyoda Corp. The Japan-GTL process can convert natural gas, shale gas and others into "clean" petroleum products (no sulfur or aromatics), such as naphtha, kerosene and diesel.

In the project, a 500-bbl/d GTL demonstration plant was constructed in Niigata city, and test operations were conducted from April 2009 through December 2011. Both the GTL process — which allows for the first time the direct use of natural gas containing CO_2 as feed —

(*Continues on p. 17*)

Scaleup for a new delignification process

This month, Borregaard Industries Ltd. (Sarpsborg, Norway; www.borregaard.com) will start up an integrated, pilot-demonstration plant to further develop a new pretreatment process for converting biomass into lignin and fermentable sugars. Located at the company's R&D Center in Sarpsborg, the pilot plant will convert up to two metric tons (m.t.) of feedstock per day. The fully integrated facility will operate continuously for at least three years, says Klaus Neumann, vice president Business Development.

The so-called BALI process (for Borregaard Advanced Lignin), consists of two main steps, explains Neumann. The first involves the fractionation of lignocellulosic biomass by means of a chemical pretreatment, which renders the lignin water-soluble and leaves behind purified fiber. In step two, the fiber is hydrolyzed enzymatically — with high yields and low enzyme consumption — to supply cellulosic sugars (C5 and C6) for further conversion, he says.

The BALI technology allows utilization of all fractions of lignocellulosic biomass — the water-soluble lignin can be converted into high-value chemicals, such as vanillin (a market for which Borregaard is a market leader), and the sugars fermented into ethanol for fuel. The process has been tested with a large variety of lignocellulosic feedstocks.

Borregaard will explore both opportunities to scale up and operate the technology, as well as licensing it to third parties, says Neumann. A first commercial plant should be reached by 2015–2016, with a capacity — depending on the application for sugars — on the order of 200,000 m.t./d of feedstock (approximately 25 million gal/yr of ethanol equivalent), he says.

New polysilicon granule-drying system boosts processing yields and purity

A novel cold-dry process makes possible the utilization of fine form-factor silicon, such as granules and sand-like fines, in the production of high-purity polysilicon for solar photovoltaic cells and semiconductors, where such fine-grained material would normally have to be sent back up the supply chain rather than into the crucible.

The patent-pending drying system, known as FlashDry, was developed by MEI LLC (Albany, Ore.; www.meillc.com) and is a critical component of a new wet-processing suite for ultrapure polysilicon. The effectiveness of the drying scheme means polysilicon makers can chemically etch, rinse and dry granular silicon, which increases yields while maintaining ultrahigh purity. "Tiny particles of silicon were thought to be impossible to dry fully in large quantities," explains David Gibbel, development engineering manager at MEI. "FlashDry opens the door to etching fine and granular polysilicon, as well as reclaimed scrap silicon material, since it can effectively and rapidly dry the etched and rinsed polysilicon."

(*Continues on p. 16*)

Base-catalyzed nucleophyllic additions with a modified zeolite

A new solid-state basic catalyst for forming carbon-carbon bonds has been developed by Masaru Ogura, an associate professor, and his research group at the Institute of Industrial Science, University of Tokyo (www.u-tokyo.ac.jp). The catalyst has been shown to accelerate the Knoevenagel condensation reaction of benzaldehyde and dimethyl malonate, which conventional, solid basic catalysts cannot do, says Ogura. And unlike existing catalysts, the modified zeolite does not require any pretreatment. The Knoevenagel condensation — a modification of the Adol condensation — is an essential reaction for forming carbon-carbon bonds.

Two years ago, the research group first developed solid base materials by introducing nitrogen into porous silica, such as zeolites. Now, they have succeeded to enhance and control the basicity of the catalyst. This is achieved by introducing inorganic-organic hybrid materials that contain an alkyl group at the basic site, using a simple methylation of the nitrogen-substituted silica, SBA-15. This methyl group donates an electron to the nitrogen atom.

NEW POLYSILICON GRANULE-DRYING SYSTEM

(*Continued from p. 15*)

When melting silicon in the production of high-purity material for use in photovoltaic cells and semiconductors, manufacturers try to add granular silicon to Czochralski crucibles to maximize yields by filling in the space between chunks of electronic-grade silicon. But unless the granular silicon is etched, rinsed and dried effectively, surface oxidation and contaminants can be introduced to the silicon crystal. The FlashDry system can remove moisture to below detectable limits in only 3 min (versus a 30-min residence time for tunnel dryers) and with 70 to 80% less energy than evaporation-based methods in conventional processing.

The first part of the two-stage FlashDry process physically removes 90–95% of the moisture from granular material, says Gibbel. In the second stage, the remaining moisture is flashed off the solid silicon particles by phase change, he adds. The FlashDry technology is contained within a polysilicon etching and cleaning apparatus that the company calls Pura. The polysilicon processing system cleans the surfaces of chunk polysilicon, as well as granules and fines, and has a footprint only one-half to one-third the size of conventional technology.

MEI has been processing customer samples in quantities as large as five metric tons in its R&D unit in Oregon, and recently offered the Pura processing system commercially.

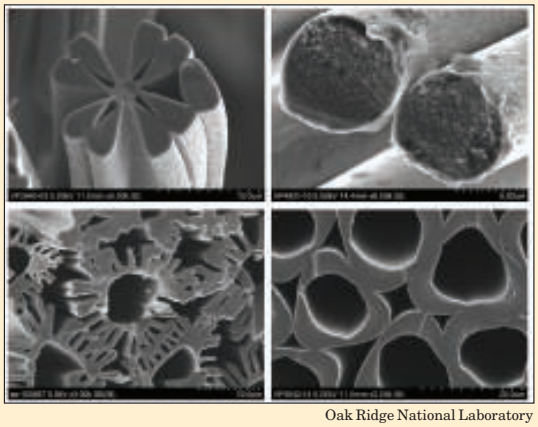
(*Continued from p. 14*)

and the catalysts demonstrated high-performance for more than 11,000 h of demonstration operations, and achieved continuous operation for more than 3,000 h. At the same time, liquid products from the Japan-GTL process were also tested. For example, 100% Japan-GTL Diesel was used for around three months by city buses.

Flame retardants

Last month, Albemarle Corp. (Baton Rouge, La.; www.albemarle.com) expanded its Earthwise platform of sustainable products by introducing a new polymeric flame retardant for use in extruded (XPS) and expanded (EPS) polystyrene applications. This new technology, licensed from Dow Global Technologies LLC, a subsidiary of The Dow Chemical Co. (Midland, Mich.; www.dow.com) will be commercialized under Albemarle's Earthwise brand, and will provide a stable, high molecular weight, non-PBT (persistent, bioaccumulative, toxic) product. ❑

Making structured carbon fibers from polyethylene



Oak Ridge National Laboratory

Researches at the U.S. Dept. of Energy's Oak Ridge National Laboratory (ORNL; Oak Ridge, Tenn.; www.ornl.gov) are developing a process that makes carbon fibers with customized surface contours from polyethylene-based fibers. The patent-pending technique uses a combination of fiber-spinning and a sulfonation technique developed at ORNL. By controlling the process conditions, the scientists are able to tune the porosity of the fibers, making the material potentially useful for filtration, catalysis and electrochemical energy harvesting, says ORNL. Carbon fibers with unique cross-sectional geometry, from hollow circular to gear shaped (photo), have been produced.

Fiber bundles are first made by a multicomponent melt extrusion-based fiber-spinning method. The fiber bundle is then sulfonated in an acid bath, which converts the plastic fiber into an infusable form — a black fiber that no longer melts. Heating to very high temperatures volatizes all other elements except carbon.

The process may also be an economical route to making lightweight materials, since the raw materials can be waste plastic bags, carpet backing scraps and salvage, which is inexpensive and abundant, according to ORNL. ■

Do you have what it takes?

ChemInnovations and *Chemical Engineering* Magazine have issued an industry-wide Call for Nominations for their 2012 Awards Program.

Award nominations will go through two rounds of judging. First, the ChemInnovations Advisory Committee will review nominations and rate each based on specific and measurable criteria. After receiving ratings, the nominations will go the second round of judging to be completed by the editors of *Chemical Engineering* Magazine.

If your plant is selected as an award finalist, a *Chemical Engineering* editor will contact you to develop an article that will be published in *Chemical Engineering* to inform the rest of the industry of your achievement.

The award finalists will receive an invitation to the 2012 Industry Awards Banquet to take place during the ChemInnovations event on Tuesday, November 13, 2012 at the Morial Convention Center in New Orleans, LA. All winners will be announced and presented during the Industry Awards Banquet.

www.che.com/CE_CI_Awards

CATEGORIES

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EPA proposes limits to new uses of potentially harmful chemicals

The U.S. Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov) has proposed that companies be required to report to the agency all new uses, including domestic or imported products, of five groups of potentially harmful chemicals. The chemicals have been used in consumer products and industrial applications, including paints, printing inks, pigments and dyes in textiles, flame retardants in flexible foams, and plasticizers.

The five chemicals EPA is targeting are polybrominated diphenylethers (PBDEs), benzidine dyes, a short-chain chlorinated paraffin, hexabromocyclododecane (HBCD), and phthalate di-n-pentyl phthalate (DnPP). The EPA is also proposing additional testing on the health and environmental effects of PBDEs.

"Although a number of these chemicals are no longer manufactured in the U.S., they can still be imported in consumer goods or for use in products. This proposed action will ensure that EPA has an opportunity to review new uses of the chemicals, whether they are domestically produced or imported and, if warranted, take action to prohibit or limit the activity before human health or environmental effects can occur," says Jim Jones, EPA's acting assistant administrator for the Office of Chemical Safety and Pollution Prevention.

The proposed regulatory actions are known as significant new use rules (SNURs) under the Toxic Substances Control Act (TSCA). The proposed rules would require that anyone who intends to manufacture, import or process any of the chemicals for an activity that is designated as a significant new use to submit a notification to EPA at least 90 days before beginning the activity. This notification means EPA can evaluate the intended new use and take action to prohibit or limit that activity, if warranted. For PBDEs, the agency will also issue, simultaneously, a proposed test rule under section 4a of TSCA that would require manufacturers or processors to conduct testing on health and environmental effects of PBDEs.

The proposed SNURs were identified in action plans the agency issued on these and other chemicals during the last two years. Information on these chemical-specific rules and the agency's action plans, including additional actions under consideration or development, can be found at www.epa.gov/oppt/existingchemicals. ❑

MORE TIME FOR FACILITIES TO MEET BOILER TUNE-UP REQUIREMENTS

On March 13, the U.S. EPA issued a "No Action Assurance (NAA) Letter" to area-source facilities that are required to conduct boiler tune-ups by March 21, 2012, under the Area Source Rule. This means that the EPA will exercise its discretion not to pursue enforcement action against sources that fail to complete boiler tune ups by the compliance date. The NAA remains in effect for area source boilers until October 1, 2012, or until the effective date of a final rule, whichever comes first.

According to the EPA, many facilities with older affected boilers notified the agency that it was not possible to meet several tune-up requirements by the original March 2012 deadline. The tune-up requires operators to conduct stack testing to measure carbon monoxide and oxygen. However, many operators said they would have to undergo alterations, such as the installation of a sampling port or platform to conduct this type of test. In addition, the tune-up also requires that combustion be optimized consistent with manufacturer specifications, and many older boilers must be repaired in order to meet such specifications. ❑

OSHA revises Hazard Communication Standard

The U.S. Occupational Safety and Health Administration (OSHA; Washington, D.C.; www.osha.gov) has revised its Hazard Communication Standard (HCS), aligning it with the United Nations' Globally Harmonized System of Classification and Labeling of Chemicals. The revised HCS will be fully implemented in 2016 and is expected to benefit workers by reducing confusion about chemical hazards in the workplace, facilitating safety training and improving understanding of the hazards, especially for low-literacy workers.

Specifically, modifications to the standard include: revised criteria for classification of chemical hazards; revised labeling provisions that include requirements for use of standardized signal words, pictograms, hazard statements, and precautionary statements; a specified format for safety data sheets; and related revisions to definitions of terms used in the standard, as well as requirements for employee training on labels and safety data sheets.

OSHA is also modifying provisions of other standards, including standards for flammable and combustible liquids, process safety management, and most substance-specific health standards, to ensure consistency with the modified HCS requirements.

OSHA says the new standard, once implemented, will prevent 43 deaths and result in an estimated $475.2 million in enhanced productivity for U.S. businesses each year.

During the transition period to the effective completion dates noted in the standard, chemical manufacturers, importers, distributors and employers may comply with either 29 Code of Federal Regulations 1910.1200 (the final standard), the current standard or both. The final rule can be viewed at http://www.osha.gov/dsg/hazcom/GHSfinal-rule.pdf. ■

ADSORPTION AND ABSORPTION

TABLE 1. ABSORBER/ADSORBER REVENUES 2012 $ MILLIONS

Technology	Industrial	Power	Total
Absorption	2,886	7,847	10,733
Adsorption	1,208	500	1,708
Ozone/ oxidation	100	50	150
Total	4,194	8,397	12,591

Robert McIlvaine,
McIlvaine Co.

Air-pollution control applications are poised to demand about $12.6 billion of adsorbent and absorbent products in 2012

Adsorption and absorption play a big role in reducing air pollution in many applications around the world. Studies show that the largest single use of absorbers this year will be to capture SO_2 from power-plant flue gas. Adsorbers will be used by many chemical process industries (CPI) to capture volatile organic compounds (VOCs) and odors. A small, but fast growing industrial segment uses ozone and oxidants in combination with absorbers.

In 2012, industrial plants are expected to spend around $2.9 billion for absorbers to capture acid gases and $1.2 billion for adsorbers to capture VOCs. Power plants will spend $7.8 billion for absorbers to remove SO_2 and HCl. They will also spend $500 million for adsorption systems to capture mercury (Table 1).

A new technology is developing to convert oxides of nitrogen (NOx) to NO_2 and then absorb it. This will add another $150 million in sales bringing total absorption/adsorption spending to over $12 billion this year.

Industrial absorption

Absorbers are used in many segments of the CPI and other industries. The chemical industry uses absorbers to capture acid gases, such as hydrogen chloride and sulfur dioxide, which are released in various processing steps. The plating industry uses absorbers to capture the fumes from the plating tanks. The food industry eliminates odorous emissions with absorbers. Other major purchasers are pulp mills, mines, steel mills and waste-to-energy plants. Since more plants in these industries are being built in East Asia than elsewhere, it is not surprising that this one region will account for 36% of the purchases this year (Table 2).

One of the biggest surprises in the absorption market is the sudden appearance of the shipping industry as a major user. There are over 100,000 large ships roaming the world's oceans and inland lakes. Many use what is called bunker fuel, which can contain up to 4% sulfur. This industry emits 12 million ton/yr of SO_2. New regulations endorsed by many countries will prevent ships from entering ports if they are not either absorbing the SO_2, or using low-sulfur fuels. The economics dictate the purchase of absorbers using seawater as the scrubbing liquor.

Adsorption

Activated carbon is the workhorse of the adsorption industry. It is used in the granular form as well as a powder. It is also impregnated onto filter media. Activated carbon is used to remove VOCs generated in the coating of products, printing, chemical processing and many other industrial applications. It is also used to purify recirculating indoor air in residential and commercial buildings. However, the revenues in this sector are not included in this analysis, which only focuses on industrial stack-gas adsorbers (Table 3).

The growth of the manufacturing base in East Asia has created a market for activated carbon that is larger than that in any other region.

Mercury removal. Power plants are also turning to adsorption. Activated carbon and other adsorbents are being used to capture mercury. New regulations in the U.S. are forcing power plants to reduce mercury by 90%. The injection of activated carbon is the route many operators will take. The carbon requirements for this application are huge. In the U.S., it is likely that the purchases by power plants for mercury removal will exceed all other environmental purchases (for both air and water). This will effectively double the market for activated carbon in the U.S.

New developments. There are a number of new developments in adsorption technology. It has been found that impregnating activated carbon with bromine enhances mercury capture. The added cost of impregnation is more than offset with the reduction in consumption.

One of the problems with activated carbon is that it ends up with the fly-ash, much of which is sold to be used in cement. The carbon, however, decreases cement strength. A solution for this has been the development of "cement friendly" activated carbons. Albemarle (Baton Rouge, La.; www.albemarle.com) is a major supplier of the cement friendly version. Several companies have developed alternatives to activated carbon that are also cement friendly. The economics and efficiency of these alternatives are still under examination.

Activated carbon is also competing with absorption. Bromine can be added to the coal. This converts insoluble elemental mercury into a soluble oxidized compound. The oxidized mer-

TABLE 2. INDUSTRIAL ABSORPTION REVENUES, $ MILLIONS

World Region	2012
World total	2,886
Africa	110
CIS	73
East Asia	1,046
Eastern Europe	111
Middle East	106
NAFTA	550
South & Central America	210
West Asia	190
Western Europe	487

TABLE 3. INDUSTRIAL ADSORPTION REVENUES, $ MILLIONS

World Region	2012
Total	1,208
Africa	38
CIS	44
East Asia	430
Eastern Europe	36
Middle East	45
NAFTA	235
South & Central America	82
West Asia	73
Western Europe	221

cury is then absorbed along with the SO_2. About half the plants in the U.S. will take this approach rather than use activated carbon.

Power plant absorption

The biggest use for absorption technology is in power plants (Table 4). Coal-fired generators around the world generate 60 million tons of SO_2. About 30 million tons are captured by absorption. The remaining 30 million tons are discharged to the atmosphere, where the most serious effect is to react with ammonia and calcium in the air to form submicron sulfate particles. These fine particles are very damaging to human health.

There has been continuous progress to make these absorbers more efficient and cost effective. Most use either the spray-tower or tray-tower design. The improvements have been in the two following areas:

- Higher efficiency due to better flow patterns
- Less scaling due to better chemistry control

Ozone and oxidation

A small but rapidly growing market segment involves the use of ozone or oxidation chemicals to convert NOx to NO_2. The conversion results in a soluble compound that can be captured by an absorber. This same approach can be utilized to deal with odors and organic compounds.

Ozone can be effective in several ways. Here are some of the ways it reacts:

$$NO + O_3 = NO_2 + O_2 \quad (1)$$

This is a favorable reaction because NO_2 can be absorbed.

$$VOCs + O_3 = CO_2 + H_2O \quad (2)$$

This is a favorable reaction because it eliminates the VOCs.

$$H_2S + O_3 = SO_2 + H_2O \quad (3)$$

This is good for odor reduction.

$$Hg + O_3 = HgO + O_2 \quad (4)$$

This is very good because it renders the mercury soluble so that it can be captured in the scrubber.

TABLE 4. POWER PLANT ABSORBER REVENUES, $ MILLIONS			
World Region	2012	World Region	2012
Total	7,847	Middle East	108
Africa	77	NAFTA	1,854
CIS	0.00	South & Central America	37
East Asia	4,742	West Asia	88
Eastern Europe	319	Western Europe	618

BOC, which is now part of The Linde Group (Munich, Germany; www.linde.com) patented a system to combine the ozone generator with a scrubber that would absorb the soluble NO_2 created by the NOx reaction with ozone. This system was licensed to DuPont (Wilmington, Del.; www.dupont.com), which has sold a number of systems for petroleum refineries.

Another approach is to use hydrogen peroxide instead of ozone. Some breakthroughs by the URS Corp. (San Francisco, Calif.; www.urscorp.com) and FMC Corp. (Philadelphia, Pa.; www.fmc.com) partnership have resulted in efficient removal of the NO_2 in downstream scrubbers where there is a high sulfite content in the scrubbing liquor. Inhibited oxidation lime systems have high sulfite levels. This technology is cost effective for smaller, older utilities.

One of the biggest applications for ozone technology is lift stations, which are used to elevate sewage for further gravity flow to a sewage treatment plant. There are other odor emission points in the treatment process that can be ducted to small units or to a combined large unit

Ozone can be used to reduce both H_2S and NH_3. The wet scrubber approach using ozone has been compared to biofilters with a pilot plant installed by Xylem Wedeco GmbH at a municipal plant in Osnabrueck, Germany. Results were reported by A Reid, J. Mielcke and M. Kampmann of Wedeco at the IOA World Congress in Strasbourg in 2005.

During the testing of the pilot scrubber with ozone versus the existing biofilter, the biofilter achieved an 82% ammonia reduction, while the scrubber with ozone achieved an efficiency of 98%. The reduction in H_2S was also superior in the wet pilot unit. This leads to the conclusion that the wet scrubber with ozone should be selected when anticipated odor levels are high or emission limits are low. Since there is a very low odor threshold (0.002–0.15 ppm) for H_2S and a 5 ppm threshold for ammonia, high reduction levels are often required.

The estimated cost of the scrubbers is higher at €0.70 compared to €0.55 per 1,000 m^3. But the cost is not prohibitive and the efficiency is necessary in many cases. ■

Edited by Dorothy Lozowski

Author

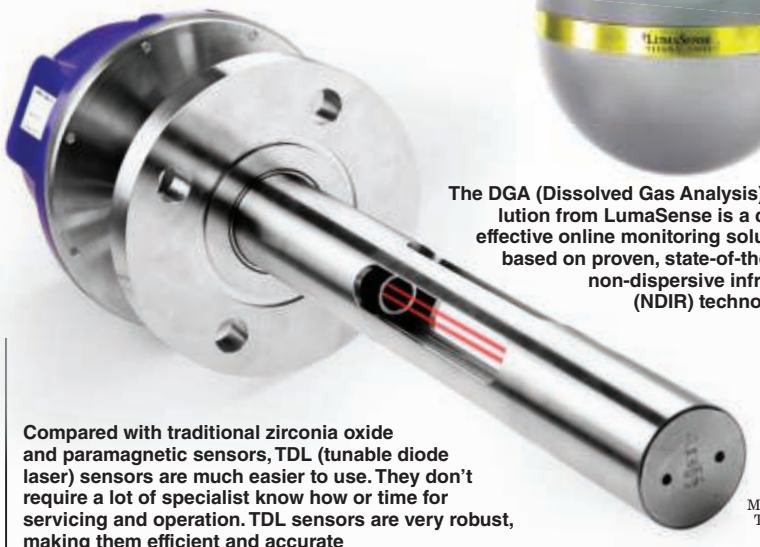
Robert McIlvaine has been producing market information reports for the environmental, energy, contamination control and process industries for over 30 years. Visit his website at: www.mcilvainecompany.com for more information.

THE SENSITIVE SIDE OF CHEMICAL PROCESSING

Advanced sensors reduce costs via reliability, digital designs and in-situ measurements

LumaSense

The DGA (Dissolved Gas Analysis) Solution from LumaSense is a cost-effective online monitoring solution based on proven, state-of-the-art non-dispersive infrared (NDIR) technology



Compared with traditional zirconia oxide and paramagnetic sensors, TDL (tunable diode laser) sensors are much easier to use. They don't require a lot of specialist know how or time for servicing and operation. TDL sensors are very robust, making them efficient and accurate

Mettler Toledo

As in almost all other aspects of producing chemicals, processors are looking for cost-effective sensing solutions. And they won't be disappointed by the newest offering of sensors for the chemical process industries (CPI). Gas and pH sensors, as well as spectrometers, are experiencing noteworthy advancements that allow the technologies to reduce costs via reliability, digital and intelligent design and in-process measurement.

"The big thing in sensors is reliability and ease of use, which help chemical processors save money in the end," says Fred Kohlmann, product business manager with Endress+Hauser (Greenwood, Ind.; www.us.endress.com). "As competition increases, chemical processors are looking to maximize both products and manpower and get greater yields. And that goes hand in hand with measuring a variety of parameters in a way that is better, faster and less expensive than it has been done in the past."

"Expense" means not only the price tag for the sensor itself, but also relates to operator friendliness and reliability. "Calibrating in the field can be tedious and time-consuming," says Stefan Van der Wal, marketing segment manager for the chemical industries with Mettler Toledo (Urdorf, Switzerland; www.mt.com). "Typically analytical instruments, regardless of the parameter they measure, are not at all easy to operate compared to transmitters that deal with physical parameters, such as temperature or pressure."

Troubleshooting sensor problems is also often considered a difficult and time-consuming endeavor. "Usually the whole measuring loop needs to be taken into account," says Van der Wal. "That means the sensor, the cable and the transmitter, as each of these can be experiencing a problem. While the sensor can be simply broken, coated or in need of recalibration, the cable and signal may also experience electromagnetic interference. On the transmitter side, wiring problems may be the cause of measurement failure."

Digital, intelligent sensors

For this reason, the introduction of digital and intelligent sensors has made huge leaps toward eradicating these problems, while reducing the associated labor and loss of productivity costs. Oxidation-reduction potential (ORP), pH, conductivity, dissolved oxygen and several other parameters have benefited from the digitalization of the electrode output signal and the intelligence that has been integrated into the technology.

Mettler Toledo has used this technology to develop the Intelligent Sensor Management (ISM) platform, which allows the electrode itself to alert operators when it needs to be replaced. The onboard intelligence includes a circuit board in the head of pH electrodes, or other sensors, which harbors a sophisticated algorithm that collects various process and sensor status data. Through continuous dynamic calculations, the ISM electrode is capable of predicting when its reliable operating life will end under the past and current process conditions.

Similarly, it will alert users when recalibration is required, which encourages predictive maintenance based on when the sensor feels it is necessary. And because the ISM "sensors" are self-configuring, the maintenance engineer needs to spend very little time at the measurement point. Upon connecting, the sensor starts to measure immediately. Any sensor in need of recalibration can be taken from the process to the workshop, where it can be recalibrated using a laptop instead of a transmitter.

Endress+Hauser has a similar technology in its Memosens line. This sensor technology offers inductive

plug-in connections with integrated intelligence that allows data relating to the process and sensor to be saved and put to further use in the plug-in head. This means that the sensors can be calibrated centrally in a laboratory under constant and ideal conditions. Non-contact digital signal transmission optimizes pH measurements and prolongs the operating life of the sensor by up to 40%, says Tracy Doane-Weideman, U.S. product manager for analytics with Endress +Hauser.

In situ-sensing

Meanwhile, there's also an increasing demand for in-process sensors of all kinds. "Customers are realizing the cost benefits of taking measurements directly in the process rather than using sample extraction and conditioning equipment," says Jean-Nic Adami, head of business development for gas analysis with Mettler Toledo. "And because safety is always a concern when it comes to gas monitoring, in-situ oxygen sensors are preferred because they have a very rapid response."

For these reasons sensors that employ laser technology for gas analysis are attracting a lot of attention, particularly now that such sensors have become more affordable. Tunable diode-laser (TDL) spectroscopy detects how much light has been absorbed from a narrow-frequency laser source as it passes through the gas stream, says Adami. From this, the sensor's analyzer can determine how much of a particular gas is present. Most TDL systems are of a cross-duct design, which necessitates careful alignment between the laser source and the detector; but newer designs feature a probe attached to the laser source that reflects it back to the detector, so alignment is not required.

Compared with traditional sensors, TDL sensors are easier to use, more robust and can measure accurately even if there's dust and moisture in the gas, notes Adami.

Eric Bergles, vice president of sales and marketing with BaySpec (San Jose, Calif.), also sees demand for in-line process monitoring using spec-

Mettler Toledo

Mettler Toledo's EasyClean automated cleaning and calibration systems optimize measurement performance and reduce maintenance load associated with these tasks

SENSOR MANUFACTURERS

BaySpec	www.bayspec.com	LumaSense	www.lumasenseinc.com
Endress+Hauser	www.us.endress.com	Mettler Toledo	www.mt.com

trometers. "This type of spectroscopic measurement allows efficiencies on the production line thanks to realtime feedback that permits adjustments to be made on the spot," he says.

The biggest benefit, notes Bergles, is the realtime decision making this type of measurement encourages. "It provides the ability to precisely monitor what's going on in the reaction," he says. "Before in-process technologies there were recipes and experiments in the laboratory that tried to replicate the process, but there was no real way to know what was going on in the reaction until after the fact, when it's too late. The ability to measure during the process prevents bad batches, waste and facility overhead. It allows a streamlined, decision-based process."

Raman spectroscopy technology assists with this type of monitoring. For Raman spectroscopy, both excitation and detection are achieved in the visible or near infrared (NIR) range, but the obtained spectral information is in the IR range. Detection of light in the visible/NIR range is generally much easier than in the IR range since it is less susceptible to thermal noise.

While the technology has been available for quite a while, until recently it was expensive and not portable. Now, less expensive, but powerful narrowband lasers, high efficiency gratings and optimally cooled detectors allow Raman spectrometers to be made in portable, even handheld, instruments at a fraction of the cost of traditional research instruments, says Bergles.

Lumasense also recognizes the cost benefits of moving measurements out of the laboratory and onto the floor, as well as the ability to measure multiple points. "We find customers are looking for value-added gas sensors that can sense multiple points and be deployed easily in different points around the plant," says Prabhu Sountarrajan, business unit manager with LumaSense (Santa Clara, Calif.; www.lumasenseinc.com).

As a result, the company offers its nondispersive infrared (NDIR) gas-sensing technology, which uses a broadband IR emitter to cover all of the wavelengths of interest for a given set of gases to be measured. Optical Band Pass filters allow that portion of IR wavelengths at which a specific gas absorbs IR energy. The technology offers high reproducibility between production runs, automated pre-inspection, set up, calibration and final verification and modular functionality for servicing. ❑

SENSOR PRODUCTS

The following are descriptions of additional sensor products

Vision sensor

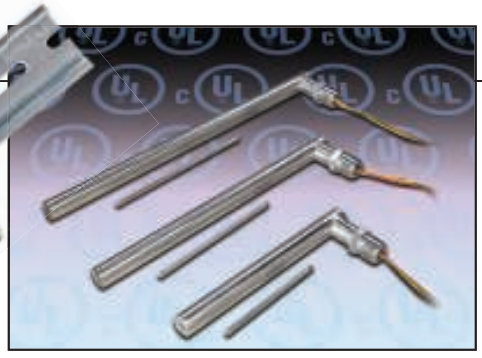
The IV vision sensor (photo, p. 26)combines some of the functionality of machine vision and traditional sensors in a single system and can handle a range of presence detection applications. The sensor's standard equipment includes high-intensity illumination, high-performance lenses and a selection of eight different sensor heads to enable sharp, clear, stable images. The IV camera selection includes close-, medium- and long-range models. It complies with the IP67 enclosure rating and can be used in dusty or wet environments. — *Keyence Corp. of America, Elmwood Park, N.J.*
www.keyence.com

Keyence

Signal converters

CTC Series Signal Converters (photo) allow users to employ an existing standard 5-A secondary CT (current transformer) or low voltage ProteCT current transformer with non-contact ranges as low as 0–5 A over a conductor to produce a standard 4–20-mA two-wire,


NK Technologies


Macro Sensors

loop-powered signal. With DIN rail mounting and a 24-V d.c. loop-powered supply, the series provides snap-in installation that requires no calibration because the primary current transformer ratio provides the scaling required without any installer intervention. In some applications, using a two-piece solution consisting of a current transformer and separate signal converter works better than using a one-piece sensor. A two-piece solution is also suitable when the system is supplied with bus bars, making installation of a standard one-piece current sensor difficult. — *NK Technologies, San Jose, Calif.*
www.nktechnologies.com

Linear position sensors

Suitable for use in hostile environments, HLR Series LVDT linear position sensors (photo) are rated for operation to 212°F. Constructed entirely of stainless steel for environmental robustness, the sensors offer contactless position measurement for critical applications. The units are also suitable for throttle-position sensing, height measurement and realtime position sensing for valves in chemical process plants. Available in full-scale measurement ranges of ±1–10 in., the sensors feature repeatability, typically better than 0.01% of full scale and non-linearity of less than 0.25% full range output. — *Macro Sensors Inc., Pennsauken, N.J.*
www.macrosensors.com

Pressure, temperature sensors

Model AST20PT stainless-steel-media isolated pressure and temperature sensors and Model AST6PT explosion-proof pressure and temperature transmitters (photo, p. 27) can be used for low-power systems to provide both a pressure and temperature reading with the power consumption of one sensor. Incorporating a microprocessor-controlled design, along with one-piece body construction, both models offer high-accuracy pressure and temperature measurements. Both units are available in various temperature readings from 0 to 250°F. Models AST46PT is offered in pressure ranges up to 20,000 psi and Model AST20PT is available in pressure ranges up to 45,000 psi. — *American Sensor Technologies, Mt. Olive, N.J.*
www.astsensors.com

American Sensor Technologies

TURCK

Electro-Chemical Devices

high-temperature service up to 392°F at pressures of 250 psig. At temperatures below 212°F, the sensor is rated for pressures up to 400 psig. It features a stainless steel outer body and center electrode, separated by a polyether ether ketone (PEEK) internal insulator. Potential leak paths are double sealed with EPR O-rings for onstream reliability. The sensor is suitable for use in any high-pressure steam boilers. — *Electro-Chemical Devices, Irvine, Calif.*
www.ecdi.com

Combo gas sensors

Designed to be calibrated in-situ with a push of a button using normal room air, the TR25OZ oxygen sensor and oxygen, carbon-dioxide combination sensor can be monitored offsite or manually calibrated. For oxygen or carbon-dioxide storage monitoring, under normal conditions, no calibration is required. The sensors support both the industry-standard 4–20-mA protocol used in process controllers and RS-485 for advanced applications. — *CO2Meter.com, Ormond Beach, Fla.*
www.co2meter.com

Proximity sensor

Available in top-facing or front-facing models, the Q42 long-range, inductive proximity sensor is made with FDA-rated materials for wash down applications. The sensor features a stainless-steel connector and PA12 thermoplastic housing that delivers resistance to chemicals and caustic cleaning agents, as well as shock from impact. The family of sensors includes 12-, 18- and 30-mm dia. barrels with sensing ranges between 4 and 30 mm. It offers a sensing range of 50 mm to all types of metals, eliminating the need to change the position of the sensor for different metal applications, but also reduces the number of sensor types needed for plant operations. — *Turck, Minneapolis, Minn.*
www.turck.us

Conductivity sensor

The CSX2 conductivity sensor (photo) is a two-electrode sensor that measures electrolytic conductivity over a range of 1.0–50 microseconds. It is designed for

Hall-effect sensor

The RTY Series Hall-effect rotary position sensor provides a variety of options, such as sensing range, pinout and voltage, that allow users to customize the sensor configuration to meet specific application needs, especially in harsh environments. The solid-state Hall-effect technology provides non-contact and low torque actuation that reduces worn-out mechanisms and provides a minimum 12-mo. cycle product life. The IP67-sealed package has an integral connector. The integrated reverse-polarity protection provides protection against installation errors. Industry-standard ampere termination, 32 mm pitch, North American and European pinout styles and the compact package provide drop-in replacement capabilities in existing applications. — *Honeywell Corp., Morristown, N.J.*
www.honeywell.com ■

Joy LePree

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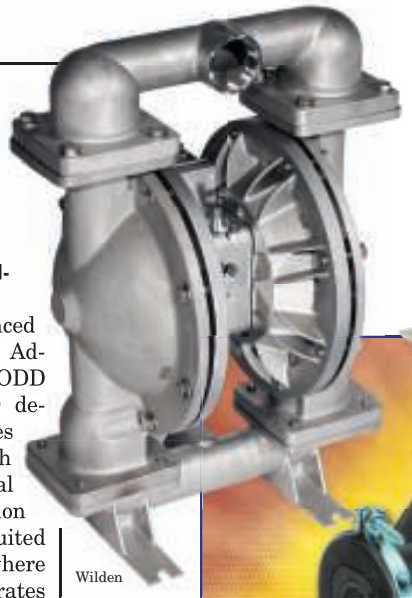
FOCUS ON

Pumps



Watson-Marlow Bredel Pumps

Wilden

Moyno

Neptune

Use these pumps where product containment is important

This company recently announced the availability of its PX800 Advanced Series Stainless Steel AODD Pump (photo). The new PX800 design is center-ported and features a full 51-mm (2-in.) flow path and threaded 51-mm horizontal fluid connections. This construction makes the PX800 pump well suited for liquid-transfer applications where product containment, high flowrates and efficiency are required. Additionally, the footprint of the PX800 Advanced pump matches that of the company's Original Series PX8 (clamped) Stainless Steel AODD pump, which enables "drop-in" replacement of an Original PX8 pump with no need to disturb existing piping. The PX800 model features bolted construction, and is constructed with a 316 stainless-steel wetted path, featuring BSPT or NPT threaded inlet and discharge connections, and a variety of elastomer options, including Neoprene. The design of these pumps allows them to deliver flowrates as high as 176 gal/min (665 L/min) at operating pressures up to 8.6 bars (125 psig). — *Wilden, an operating company within Dover Corp.'s Pump Solutions Group (PSG), Grand Terrace, Calif.*
www.wildenpump.com

Peristaltic pumps for abrasive materials applications

The heavy-duty SPX hose pumps (photo) are well-suited for challenging environmental applications, such as sludge handling, filter press and centrifuge feed, and lime and carbon slurries. Advanced hose technology enables the SPX to pump grit-filled sludge dependably and reliably. SPX hose pumps are virtually maintenance-free, with no expensive seals to replace, no check valves to clog, and no rotors, stators or lobes to wear out. Unlike other pump types, the highly abrasive nature of sludge does not affect pump life. With its self-loading design, hose replacement is quick and easy. — *Watson-Marlow Bredel Pumps, part of the Watson-Marlow Pump Groups, Wilmington, Mass.*
www.bredel.com

Diaphragm metering pumps for water applications

The Series 7000 mechanically actuated, diaphragm metering pump (photo) has specifically been designed with water and wastewater applications in mind. The mechanical design of the Series 7000 eliminates the use of contour plates on the liquid side of the diaphragm while the simple, straight-through valve and head design allows for improved flow characteristics. The Series 7000 is self-priming and has a maximum capacity range up to 300 gal/h at 150 psi. — *Neptune, an operating company within Dover Corp's PSG, North Wales, Pa.*
www.neptune1.com.

These pumps provide corrosion resistance

This company's 500 Series 301 Pumps (photo) are suitable for use in corrosive, chemical dosing and transfer applications. The 500 Series 301 Pumps feature a reverse covered-seal design between the rotor and shaft, which eliminates metal exposure to fluids. Phenolic housings and rotors offer superior corrosion resistance. Hose connections, resilient cushion and cradle mounting provide easy installation, maintenance and replacement. Suitable for direct or belt drive, the 500 Series 301 Pumps offer capacities ranging from 0.45 to 13 gal/min and pressures up to 25 psi. — *Moyno, Inc., Springfield, Ohio*
www.moyno.com

Gentle material transfers are this pump's specialty

The MasoSine pump (photo, p. 31) is designed to transfer material gently and economically, making it well

Note: For more information, circle the 3-digit number on p. 61, or use the website designation.

Watson-Marlow

Watson-Marlow Masosine

suited for algae transfer or for pumping enzymes. MasoSine pumps provide consistent flowrates and minimize damage with a non-contacting rotor liner. These economical pumps offer speed of transfer, powerful suction, quick unloading time and ease of maintenance. For applications, such as in biofuels, the MasoSine's consistent flowrates prevent damage to the live products and even allow them to multiply during transfer. With a low horsepower requirement the MasoSine pumps generate at least a 20% energy savings over many other pump types, according to the manufacturer. With only one shaft, one seal and one rotor, maintenance is minimal. The pulse-free flow characteristics benefit flow control and heat transfer as well as filtration, and the pump handles flows up to 440 gal/min. — *Watson-Marlow Masosine, part of the Watson-Marlow Pump Groups*, *Wilmington, Mass.*
www.masosine.com

A chemical metering system that is suited up to 100 psi

Using peristaltic pumping, this system (photo) delivers metering accuracy of ±0.1% and far better reliability than diaphragm pump systems, according to the manufacturer. There are no back-pressure regulators or de-gassing valves required. Designed for easy operation and low-maintenance metering of water-purification chemicals, such as sodium hypochlorite and ferric chloride, these chemical metering systems are also easy to install. A turn-key wall- or floor-mounted solution for precision metering — including the pumps, valves, pressure relief, gages, calibration column, leak detection and all interface pipe work can be provided. These systems are suited for chemical injection up to 100 psi, can indefinitely run dry without damage and provide up to 30 ft of suction lift. — *Watson-Marlow, Wilmington, Mass.*
www.wmpg.com

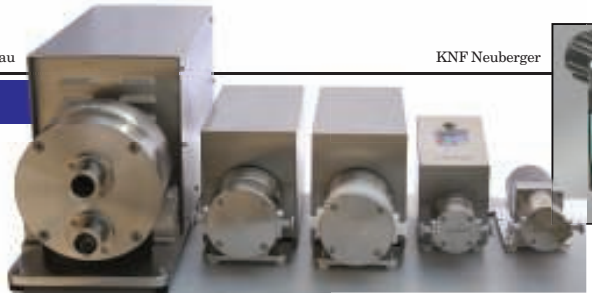
Pumps satisfy both E.U. and U.S. standards

The Flux Food Series of pumps are certified for food contact applications. They satisfy E.U. Regulations 1935/2004 and 10/2011 for plastics that come into contact with food and bear the European glass-fork symbol (photo). They also satisfy U.S. Food and Drug Administration (FDA) requirements. The series can cover a wide range of applications ranging from low- to high-viscosity fluids. All Flux Food pumps can be completely dismantled and cleaned quickly. The new pumps come in all stainless-steel, and include the barrel and container pumps FP 427 Food; FP 430 Food, with explosion protection for alcohols; and the eccentric worm-drive pump, F 560 Food, in a flange and transmission model for high-viscosity media. — *Flux-Geräte GmbH, Maulbronn, Germany*
www.flux-pumpen.de

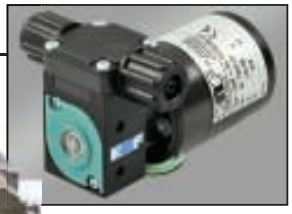
Circle 22 on p. 61 or go to adlinks.che.com/40267-22

Focus

Almatec Maschinenbau



KNF Neuberger



These pumps primarily serve high-purity applications

Quattroflow positive displacement (PD) pumps (photo) incorporate a four piston-diaphragm technology with no mechanical seals that is driven by an eccentric shaft and motor. Available for multiple and single-use applications, Quattroflow PD pumps primarily serve the pharmaceutical and biotechnology industries that require high containment, purity and cleanability, and are best known for transferring shear-sensitive media of aqueous solutions and biological products without damage. Quattroflow pumps feature wetted housing parts constructed with electro-polished 316L (Basel Standard II, ferrite content <1%) stainless steel, while the valves are made of EPDM and the diaphragms of EPDM/PP compound. The Quattroflow product line consists of four sizes — QF150, QF1200, QF4400 and QF20K — with capacities of 2.6 to 333 L/min (0.7 to 88 gal/min). — *Almatec Maschinenbau GmbH, an operating company within Dover Corp.'s PSG, Kamp-Lintfort, Germany*
www.almatec.de

A micro-diaphragm pump for high-pressure applications

The new KNF Type NF1.25 micro-diaphragm pump (photo) introduces a high-pressure solution for dosing or transferring liquids or liquid-gas mixtures at flowrates up to 300 mL/min. This small and powerful pump is engineered to operate either intermittently or continuously against pressure up to 6 barg (87 psig) over the pump's entire lifetime. Versions can be specially developed to handle even greater pressure up to 10 barg (145 psig). Typical applications include analyzers, cleaning and disinfectant devices, water treatment systems, fuel cells and semiconductors. These pumps are self-priming, can run dry, and require virtually no maintenance over a long lifetime, says the manufacturer. They offer chemical resistance, and most neutral and aggressive liquids can be handled without risk of corrosion or other damage. Specialized complementary accessories can be supplied, including an innovative anti-vibration mounting plate with the capability to dramatically reduce vibration levels and audible noise. Pumps can be mounted in any position. — *KNF Neuberger GmbH, Freiburg-Munzingen, Germany*
www.knfoem.com ■

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ACHEMA 2012

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Achema 2012 — the 30th World Exhibition Congress on Chemical Engineering, Environmental Protection and Biotechnology (June 18–22; Frankfurt am Main, Germany) — is approaching, and organizers at Dechema e.V. (Frankfurt, Germany; www.dechema.de) are optimistic that the attendance and exhibitor totals will outpace those of the 2009 event, which recorded a total of 3,767 exhibitors and over 173,000 visitors.

Held every three years, Achema is the global summit for technology developers, suppliers and users in the chemical process industries (CPI), covering all aspects of chemical processing, from the laboratory all the way to world-scale production plants and packaging technology.

The hot topics at Achema 2012 are energy (energy storage technologies and energy-saving plants) and resources — the increased use of renewable resources coupled with the application of biotechnological processes.

Throughout the week, over 900 lectures will be presented in the Congress program, which covers the entire spectrum of process engineering, pharmaceutical production and biotechnology. With 18 parallel tracks running every day, visitors are encouraged to make use of the congress planner (http://kongress.achema.de/en/congressplanner).

For more on Achema 2012, see *Chem. Eng.,* March, pp. 32I2–32I4, as well as the extensive online tools available at http://achema-content.dechema.de. *Chemical Engineering* will be covering all the activities and reporting them in the *Achema Daily* — a bilingual, daily newspaper that will be co-produced with Vogel Media (Würzburg, Germany) and distributed at the Frankfurt fairgrounds. A digital version of the *Achema Daily* will also be available at www.che.com for those readers unable to attend the event.

What follows is a small sample of some of the new products that will be on display at the exhibition.

Nine different I/O modules are available here

The Antares plus remote I/O (photo) can be connected to any current control with various bus systems (Profibus-DP, ProfiNet, Ethernet IP, Modbus TCP). There are nine different I/O modules available in the form of digital and analog inputs and outputs. In addition, with Profibus-DP, high system stability can be achieved through the redundant structure of the two top modules. A power-supply unit allows the supply of up to 32 modules. A large number of sensors and actuators can thus be connected. The system is certified for ATEX Zones 1 and 2 (gas) and ATEX Zones 21 and 22 (dust). Hall 11.1, Stand E76 — *Bartec GmbH, Bad Mergentheim, Germany*
www.bartec.de

Put your iPad to work with this augmented reality software

While leveraging mobile devices, such as tablets, smart phones and head-

Note: For more information, circle the 3-digit number on p. 61, or use the website designation.

Berkefeld

Beot Inorganic Membrane Separation Equipment

mounted displays, the UBIK software allows the creation of flexible, high-performance object models that are capable of consolidating data from almost any source. Equipped with XML capabilities, the server can integrate data from third-party systems by means of international standards, such as ISO 15926. This can happen whenever it is needed — as a one-time import, at regular intervals or immediately upon request. The software displays tag information in the form of floating bubbles (photo, p. 32I-1) in realtime, faded into the camera image. By tapping on a specific tag, further available data can be retrieved from the server via UMTS, HSDPA, LTE or Wi-Fi. Hall 9.2, Stand D32 — *Augmensys GmbH, Klagenfurt, Germany*
www.augmensys.com/de

Proven cooling technology for sulfuric acid plants

In order to make sulfuric acid from elemental sulfur, catalytic exothermic processes are used. These require special cooling sections. This construction company uses water-tube boilers (photo, p. 32I-1) to cool down the gases containing SO_2, which are produced in the combustion chamber. Several heat exchangers — precisely matched to the process requirements for the catalytic converter — cool the gases down to the required temperatures. A constant temperature from the waste-heat boiler is maintained by internal or external gas- or steam-side bypasses, which can be regulated. This company has built many such waste-heat boilers, which are now in use all over the world. Hall 9.1, Stand D22 — *Oschatz GmbH, Essen, Germany*
www.oschatz.com

Crane ChemPharma Flow Solutions

One mixer performs five process steps for making food products

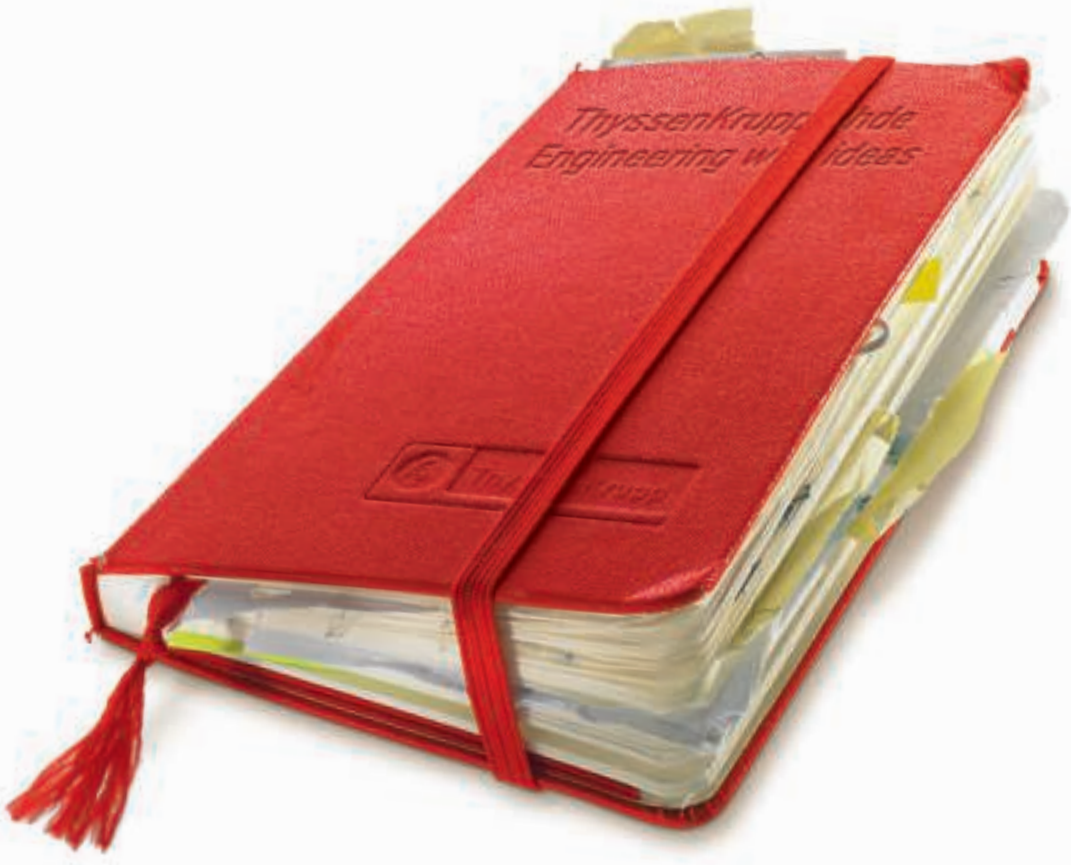
This company has launched the new 5-in-1 Pegasus Mixer (photo, p. 32I-1) for multifunctional preparation of food products. A single investment allows performance of five process steps: mixing, vacuum coating, drying, sterilization and acidulation. This new variant of the existing Pegasus Mixer is especially suitable for producing aromatized products quickly, efficiently and homogeneously in situations where high hygiene standards apply. Typical applications include tea, cereals, sweets and snacks. Hall 5.0, Stand D17 — *Dinnissen Process Technology B.V., Sevenum, The Netherlands*
www.dinnissen.nl

Abrasives and corrosives are not a problem for this diaphragm

Among this company's extensive line of fluid-handling products being showcased at Achema is the Saunders XY Diaphragm (photo), which offers increased erosion resistance in both corrosive and abrasive applications, including fertilizers, metals, chemicals and mining. The new diaphragm provides enhanced flex life, resulting in reduced down time and improved productivity therefore equating to a lower cost of ownership, says the company. The diaphragm demonstrates a 25% improvement in elastic recovery, which means a better sealing performance and reduced emissions, and is considered leak-free in accordance with the standards MSS SP-88 and BS EN 12266-1. This diaphragm is fully compatible with all existing Sanders Industrial Diaphragm Valve (IDV) product ranges — both for new installations and as a replacement in existing valves. Hall 8.0, Stand C94 — *Crane ChemPharma Flow Solutions, Cincinnati, Ohio*
www.cranechempharma.com

Sintered metal filters in many shapes, sizes and materials

This leading Chinese manufacturer of sintered-metal powder filters (photo) can produce filter elements tailored to an application. Product types include cartridge, cylinder, tube, disc and plate filters; as well as spargers, cups, fittings and others. Filter ratings range from 0.2 to 200 micron. Materials available include stainless steel (316, 316L, 304, 304L, 310, 904), nickel, Monel 400, Iconel 600/625, titanium, Hastelloy and more. Products are certified for quality assurance under ISO9001:2008. Hall 6.0, Stand D78 — *BEOT Shijiazhuang Beot In-*



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JUMO

Sipos Aktorik

organic Membrane Separation Equipment Co., Hebei, China
www.beot-filters.com

A thermostat that is robust, reliable and flexible

The new exTherm-AT surface-mounted thermostat (photo) features three qualities: robustness, with an approved operating temperature as low as –55°C; reliability, proven by 250,000 tested switching cycles; and flexibility, thanks to a wide range of options for equipment and combinations. The thermostat can be used in all areas with a potentially explosive atmosphere, even to the surrounding area of pipe-tracing systems, where the primary concern is monitoring the maximum pipe temperature, and to distillation plants, where thermal processes are controlled. The device has ATEX approvals to Zones 1 and 2 (gas) or Zones 21 and 22 (dust), and zone separation between zones 0 and 1 is possible with special thermowells. Hall 11.1, Stand F62 — *JUMO GmbH & Co. KG, Fulda, Germany*
www.jumo.de

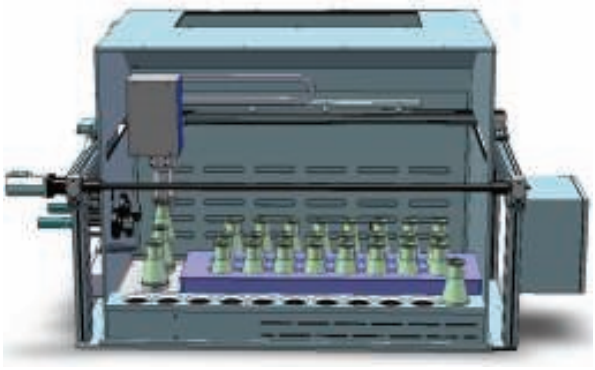
Support over 200 actuators with this master station

This company is exhibiting the HiMod extreme precision actuator range. Offering advanced flexibility and accuracy, HiMod actuators (photo) support the most challenging control-valve requirements, says the company. Capability in realtime, distributed control is also enabled with the company's SIMA master station, which provides intelligent fieldbus-based automation and supports over 200 electric actuators. The Sipos 5 Flash range of rotary, linear and part-turn actuators will also be featured at Achema. Hall 9.0, Stand E35 — *Sipos Aktorik GmbH, Altdorf, Germany*
www.sipos.de

Destroy biofilms with this solid-state catalyzer system

As an effective countermeasure to biofilms, this company has developed a solution based on solid-state catalyzers (photo, p. 32I-2). The core of the process is the VWS MOL catalyzer technology. So-called biotensides, produced by solid-state catalyzers, ensure efficient removal of biofilms. By means of electrostatic charging, free germs are attracted and the biotensides are produced by their fragmentation. The biofilm is subsequently killed and removed from the surfaces of heat exchangers. Two variants have been demonstrated: for the production of biotensides, in the VWS MOL Clean system, small amounts of MOL aktivE30 are added; in the VWS MOL LIK system, light of a specific wavelength is used. Hall 6.1, Stand B98 — *Berkefeld, VWS Deutschland GmbH, Veolia Water Solutions & Technologies, Celle, Germany*
www.berkefeld.de

Nucomat



Nuclear containment technology for robotic chemical manipulations
With strong roots in the nuclear sector, this company has developed the Hotcell Compact (photo), a complete robotized sample-preparation system embedded into a completely closed fume-extraction cabinet. A sample is identified by the RoBin software and, based on this, a pre-programmed method is activated. The sample is first placed inside the cabinet, which is then closed and an automatic sequence is initiated for acid dispensing, hotplate leaching, hotplate digestion, dilution and so on, until the prepared sample is ready to exit the cabinet. Everything is executed without any human intervention under strict health and safety regulations. Hall 4.2, Stand A54 — *Nucomat CV, Lokeren, Belgium*
www.nucomat.com

Use this surface-treatment to harden stainless steel
Stainihard NC is a process used to harden the surface of austenitic stainless steel without reducing the corrosion resistance, and in some cases, the corrosion resistance is even improved, says the company. The process is based on traditional, gas nitrocarburizing treatment for steels, but is a variant that is able to treat steels that cannot be treated with normal gas-diffusion treatments. This thermochemical process is suitable for processing individual components or large batch volumes. Stainihard NC provides a strong improvement in abrasion resistance, fatigue strength and seizing to components (photo). Applications include the food-processing industry, where the treatment reduces wear of machine parts (rotating parts, drive components, pump parts, valves, plungers and so on), while also making them easier to clean. Hall 9.1, Stand B67 — *Heat & Surface Treatment B.V., Eindhoven, The Netherlands*
www.h-st.nl

Residual leakage, media loss are minimized with these couplings
The clean-break couplings of the new CP Series (photo, p. 32I-6) were developed for water hydraulic applications and for demanding media in the chemical and medical sectors, for process technology and engineering. Ergonomic and non-squirting operation — even under residual pressure — is made possible by means of a special clean-break valve technology. The function-related residual leakage is thus minimized in such a way that very little media is lost when the fitting is disconnected. At the same time, very little foreign media enters into the pipe system when it is

Show Preview

Walther-Präzision, Carl Kurt Walther

reconnected. Couplings are made in stainless steel (as standard), and are available in nominal sizes 6, 9, 12 and 16. Hall 8.0, Stand K82 — *Walther-Präzision, Carl Kurt Walther GmbH & Co. KG, Haan, Germany*
www.walther-praezision.de

A portable tensiometer for onsite surfactant measurements
The Bubble Pressure Tensiometer BP50 (photo) is a mobile surface-tension measurement system that can be used, for example, for checking the concentration of cleaning agents onsite, checking rinsewater for surfactant residue after tank cleaning or determining the correct time for additional dosing of surfactants in electroplating baths. The BP50 can detect the surface tension that occurs just after surface formation at surface ages of between 15 and 16,000 ms, thus making it suitable for measurements of high-speed processes, such as printing, spraying and coating. The system consists of a capillary, compressor, pressure sensor and temperature sensor, all combined in a hand-held instrument for onsite measurements. Hall 4.1, Stand F50 — *Krüss GmbH, Hamburg, Germany*
www.kruss.de

This ePTFE tape saves time and money when joining large flanges
Based on this company's patented expanded polytetrafluoroethylene (ePTFE), the new Series 500 Gasket Tape for large steel flanges enables industrial plants to save time, money and trouble compared to conventional large gaskets, says the manufacturer.

W.L. Gore & Associates

SensoTech

The new gasket tape is said to deliver at least a 50% greater creep resistance than other ePTFE gasket tapes, which gives greater assurance of a secure seal, maximizing operational reliability and performance of flanged connections, says product specialist Peter Wagner. Because the user can create a gasket instantly in any shape, regardless of flange size or complexity, Series 500 Gasket Tape (photo) is a great time saver; it eliminates the time needed for large, custom gaskets to be fabricated off-site. Hall 9.0, Stand B14 — *W.L. Gore & Associates, Inc., Newark, Del.*
www.gore.com

Measure concentrations with this ultrasonic flowmeter system

A measuring and analytical system that determines concentration in any type of liquid is provided with the LiquiSonic system (photo). LiquiSonic consists of one controller and one or several sensors. The sensors are installed directly in the process, work maintenance-free, and are usually manufactured in stainless steel. The completely enclosed design, which requires neither gaskets, moving parts nor windows to the process, makes the sensors especially robust. ATEX- and IECEx-certified systems are available for use in hazardous areas. Typical applications include the precise determination of concentration of mixtures, phase detection, and neutralization or reaction motoring, such as polymerizations and crystallizations. Hall 11.1, Stand F75 — *SensoTech GmbH, Magdeburg-Barleben, Germany*
www.sensotech.com

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RheoSense

Chip technology enables hand-held viscometery measurements
The µVISC portable viscometer (photo) is this company's latest product from its core VROC technology. Based on MEMS and microfluidic technology, the viscosity measurement is performed in a small chip, and the µVISC requires only 100 to 400 µL per measurement. Measurements are performed within a minute with an accuracy of 1% of full scale (2% of reading). The device measures viscosity in centipoise, shear rate and sample temperature, and can log as many as 20 tests, each with a user-defined sample ID. Both Newtonian and non-Newtonian fluids can be measured. Hall 4.1, Stand P75 — *RheoSense, Inc., San Ramon, Calif.*
www.rheosense.com

A compact still for large throughputs of heat-sensitive materials
The patented Plate Molecular Still (photo, p. 32I-9) is capable of distilling large quantities of product (10 ton/h and more), under medium- or high-vacuum conditions. The system is suitable for applications involving temperature-sensitive substances, such as oils, fats, pharmaceuticals, vitamins methyl esters and more. The product is fed through a distribution system to the outer surface of the evaporator plates within a cylindrical vessel. In this arrangement, the heated and cooled panels lead to a high evaporation and condensation surface in the smallest possible space. As a result, the economics are more favorable when using the Plate Molecular Still compared to more expensive short-path distillation processors, says the company. Hall 4.0, Stand A68 — *GIG Karasek GmbH, Gloggnitz, Austria*
www.gigkarasek.at

Internal ring baffles improve heat transfer in glass reactors
The Stripe Jacketed Glass Reactor (photo, p. 32I-9) incorporates ring baffles inside the heat-transfer-fluid zone, thereby promoting turbulent flow for efficient heat transfer. This not only enables precise control of the process temperature, but also makes it possible to cool down to very low temperatures, such as –95°C, which has not been achievable in glass reactors before, says the manufacturer. — *Asahi Glassplant Inc., Arao City, Japan*
www.theglassplant.com

GIG Karasek

Novosep

Asahi

Ekato

The length of this chromatography bed can be hand-adjusted

The Prochrom-Bio manual biochromatography columns (photo) are available with adjustable column length as a standard feature for operation at pressures up to 5 bars. This unique design is said to be operator-friendly, allowing manual bed-length adjustments and maintenance. The piston is equipped with an inflatable gasket that ensures both easy assembly and tightness. These columns are suitable for all purification steps, such as capture, intermediate purification and polishing in both R&D and cGMP environments. Hall 6.1, Stand B70 — *Novosep, Pompey, France*
www.novasep.com

This blender outperforms extruders for viscous fluids

The blending of fine particles with viscous fluids is required for the production of highly viscous products, such as sealing and insulation materials. As an alternative to cost and energy-intensive extruders, this company has developed a

immuG Rohr + Schlauch

Outotec Oyj

new blender-design concept (photo, p. 32I-9) that is said to "markedly" reduce the energy requirements. The design of the impellers causes a continuous flow through the vessel and divides it into two zones; one of intense back mixing and another area of high shear intensity. The solid is wetted in the backmixing zone while complete dispersion of the product occurs in the shear area with plug-flow characteristics, which leads to consistent, high product quality, says the company. Hall 5.0, Stand D42 — *Ekato Group, Schopfheim, Germany*
www.ekato.com

A large pressure filter is now two times bigger

This company has scaled up the proven Larox pressure filtration (PF) technology to larger scale. The Larox PF 180 series filters (photo) are now 50% larger than the previous model. The PF 180 is almost 9 m long, 9 m high and has a maximum filtration area of up to 252 m^2. Filtration cloth of the PF 180 is continuous with only one seam and is 200 m long. The automation system of the PF 180 has also been upgraded with interactive self-diagnostic features, user manuals and an electronic spare-parts catalog with 3D images. Hall 5.0, Stand C62 — *Outotec Oyj, Espoo, Finland*
www.outotec.com

Large, rubber-lined bends for transporting abrasives

Piping-bends up to ND 900 from rubber incorporating a seamless, highly abrasion-resistant inner rubber layer (photo) completes the range of this company's products. On display at the company's stand will be a bend of dimension ND 600. Rubber bends have proven themselves in conveying applications for highly abrasive suspensions in the chemical industry, mining and environmental areas. Rubber bends provide a much higher lifetime under chaffing conditions than bends made of other materials, says the manufacturer. The process for fabricating these bends allows for continuous configuring of both the bend radius (from 1.6 × ND to 6 × ND) and bend angle (from 15 to 105 deg.). Hall 9.0, Stand D22 — *immuG Rohr + Schlauch GmbH, Walbeck, Germany*
www.immug.com

Liquid jet pumps do more than create a vacuum

This company has opened up new fields of applications for liquid jet pumps in which the pump is not only used to generate a vacuum, but at the same time to scrub gas and separate dust (photo, p. 32I-11). In the new application presented at Achema, HCl-laden exhaust gas is extracted from a tumbling dryer and scrubbed until the exhaust meets TA-Luft requirements, with simultaneous generation of a 50-mbar vacuum. The jet pump is made of conductive polypropylene (PP) with glass-fiber-reinforced plastic, and is offered as a compact unit that includes: a separator made of PP, motive fluid pumps of perfluoroalkoxy (PFA) and plate heat exchangers made of titanium. Hall 4.0, Stand F44 — *GEA Wiegand GmbH, Ettlingen, Germany*
www.gea-wiegand.de

GEA Wiegand

TMW

Make distilled water from wastewater using low-grade heat

EcoStill (photo) is based on patented multistage humidification/dehumidification (MHD) technology — a distillation process operating under atmospheric pressure, below boiling point with evaporation and condensation in air streams, without pressure or vacuum. With only one moving component, EcoStill works with low-grade heat (temperature less than 80°C) as hot water, low-pressure steam or exhaust gas. It produces distilled water that can be reused or safely discharged into the environment. Each EcoStill module can treat up to 300 m^3/yr of liquid waste and recover up to 90% of the water. Up to five modules can be assembled in parallel for treatment capacities of up to 1,500 m^3/yr. Hall 5.1, Stand D52 — *TMW, Paris France*

www.tmw-technologies.com

Cold is okay for this chemically resistant elastomer

The Perplast ICE G75LT offers a combination of "excellent" chemical resistance and low-temperature performance. This perfluoroelastomer material has been specifically developed to perform under extreme conditions, in temperatures as low as –40°C or lower. The elastomer has been formulated to provide increased resistance to a broad range of chemicals by carefully controlling the molecular architecture. Also, this material has low permeability and as a result, it is less prone to swelling, leading to extended in-service performance in valves, pumps and mechanical seals. Hall 9.0, Stand E14 — *Precision Polymer Engineering, COG Gehrckens, Pinneberg, Germany*

www.prepol.com

Filterbelts featuring double-layer weaving

This company has pioneered the double-layer weave (DLW) filter media made of synthetic yarn technology, and now offers the widest range of double-layer filter media in the market. The Tetex DLW filter media family ranges from a standard polyester fabric to polyether ether ketone (PEEK). The latest innovation is the heavy-duty line, Tetex DLW HD, a next generation filter media for vacuum belt filters. Choice of pore sizes from 7 to 150 µm, in widths up to 3.5 m (6 m on request) are available. The company also is presenting its Pharma-Grade dust filter bags for particle recovery to meet the demanding conditions imposed by regulations in the pharmaceutical industry. Hall 5.0, Stand D60 — *Sefar AG, Heiden, Switzerland*

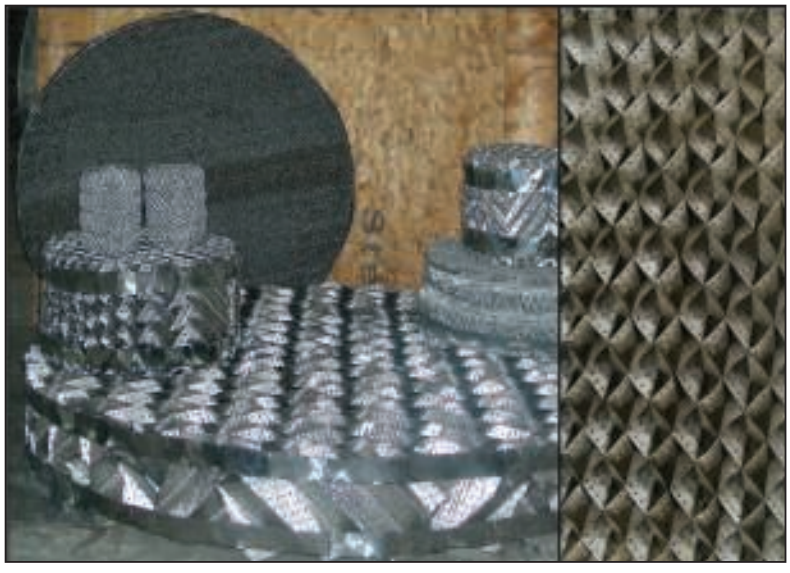
www.sefar.com

This steam trap has no moving parts

The recently launched Delta DSV energy saving steam trap has no moving parts and yet is still able to completely remove condensate while holding the steam back in the system, even in varying load or pressure conditions. The Delta DSV is guaranteed for ten years and can never fail open and pass steam. The steam trap is said to save between 10 and 20% of a boiler fuel bill through the elimination of any steam wastage, while allowing better heat transfer in the steam system through its condensate-removal ability. A full range of sizes is available — from DN15 threaded through DN200 flanged — covering pressure ranges up to 100 bars saturated steam. Hall 5.1, Stand D44 — *Delta Steam Systems, Cape Town, South Africa*

www.deltasteamsystems.com

Evergreen Technologies



SnowPure

A wide range of structured packing available here

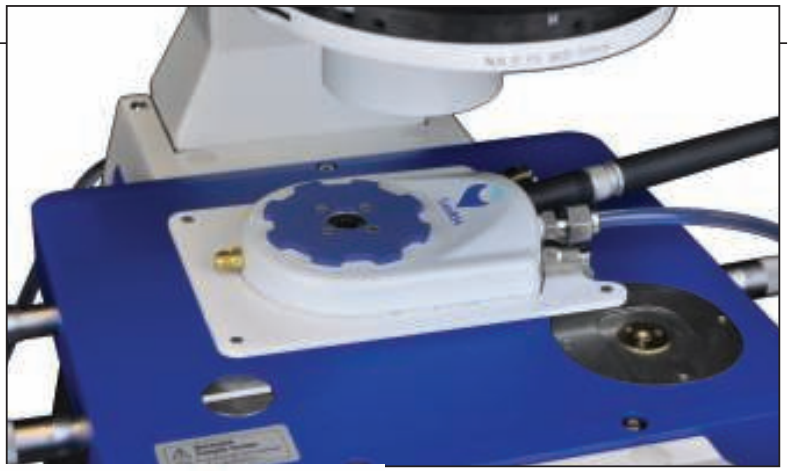
This company offers a full range of sheet metal structured packing (photo), along with a full range of column internals. This high-efficiency structured column packing covers operating conditions from vacuum to medium pressure, with specific surface areas from 70 to 750 m^2/m^3, providing a wide range of efficiency and pressure-drop requirements. The structured packing complements the company's line of wire-gauze and knitted-mesh packing products. Hall 6.1, Stand C79 — *Evergreen Technologies Pvt. Ltd., Mumbai, India*
www.evergreenindia.com

A transmitter that measures both pressure and dewpoint

The DPT146 Dewpoint and Pressure Transmitter is said to be the first transmitter available for monitoring both dewpoint and process pressure simultaneously, making it especially suitable for applications involving high-quality compressed air. Dewpoint data are constantly pressure compensated online and in realtime, which means that separate conversions are no longer needed to take possible changes in pressure into account. As one single transmitter provides two of the most important measurements for compressed air applications simultaneously, installation costs can be reduced and setup and maintenance are simplified and efficient. Hall 11.0, Stand A1 — *Vaisala, Vantaa, Finland*
www.vaisala.com

Achieve high flow with this electrodeionizer

Designed to be the highest flow EDI (electro-deionization) modules on the market, the new Electropure EXL-700



Surface Measurement Systems

Pope Scientific

EDI modules (photo, p. 32I-12) are configured to easily build ultrapure water systems, and can be used with either single- or double-pass reverse-osmosis (RO). Among the features are the company's patented Excelion membranes, non-scaling electrode system, new "never-leak" permanent O-ring seals and thin-cell technology. With the Electropure EDI thin-concentrate technology, scaling is almost eliminated and salt-injection or feed-and-bleed systems are not required. Hall 6.1, Stand C79 — *SnowPure, LLC, San Clemente, Calif.*
www.snowpure.com

This hybrid still system handles heat-sensitive substances

Extremely heat-sensitive fine chemicals and other substances are safely and efficiently separated with this Hybrid Still Technology (photo). These systems combine the gentle evaporating principle of high vacuum, dynamically mixed and transported wiped thin films with the highly efficient separation capability of fractional packed columns. Versatile designs allow onsite reconfiguration for high-vacuum molecular (short-path), distillation, evaporation or fractionation. Systems are available in sizes from 1-kg/h benchtop units to pilot and processing plants with feedrates of more than 1,000 kg/h, with construction in glass, 316L stainless steel, Hastelloy and other materials. Hall 5.1, Stand C44 — *Pope Scientific, Inc., Saukville, Wisc.*
www.popeinc.com

Study moisture-induced changes with this microscope cell

The GenRH-H (photo) is a new environmental microscopy cell with relative humidity control. The cell provides dynamic humidity control of a sample in optical, Raman, Fourier-transform infrared (FTIR) and other analysis techniques. Used in conjunction with an optical microscope, the GenRH is suitable for studying moisture-induced phase changes; relaxation, swelling and stability of particles, granules and fibers; degradation and caking of foodstuffs; deliquescence and powder stability; and more. With Raman or FTIR, the cell can be used to study hydration formation, polymorphs transitions, crystallization of amorphous compounds, and so on. Hall 4.2, Stand F66 — *Surface Measurement Systems Ltd., London, U.K.*
www.genrh.co.uk

Smart pipettes that are comfortable to use

Accumax Smart Pipettes (photo, p. 32I-14) have an ergonomic design for

fatigue- and stress-free operation with a convenient handgrip that enables long hours of pipetting. The Soft Touch requires only the lightest force for aspiration and dispensing, and a large digital display enables smaller increments and smooth volume changes. Sealing with PTFE ensures longterm performance. The devices are autoclavable and have enhanced ultraviolet resistance. Hall 4.1, Stand A62 — *Fine Care Biosystems, Gujrat, India*
www.accumaximum.com

Fine Care Biosystems

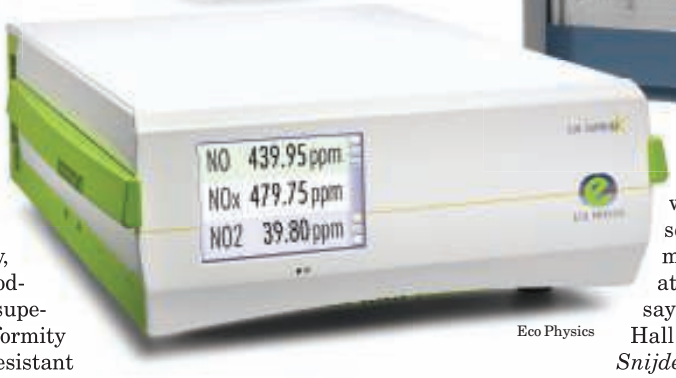
Helmer

Freezers and refrigerators with smart features

This company's refrigerators and freezers (photo) are available on all i.Series and Horizon Series models. The i.Series line features the door-mounted i.C User Interface with full-color touchscreen. It provides constant temperature monitoring, event acknowledgement, and multiple information logs that can be downloaded. Horizon Series models feature a temperature controller with an alarm and monitoring system. Refrigerators are available in laboratory, pharmacy and blood bank models from 5–56 ft^3. They offer superior chamber temperature uniformity with quick recovery, bacteria-resistant powder coating, self-closing doors, and LED lighting. Shelves, roll out baskets, and drawers provide custom storage options. Freezers are available in 5, 20 and 25 ft^3 models for laboratory and plasma storage. They feature programmable automatic defrost, bacteria-resistant powder-coated interior and exterior, and custom storage options. Hall 4.2, Stand A29 — *Helmer, Noblesville, Ind.*
www.helmerinc.com

Measure NOx over a very wide concentration range

The CLD 811 nitrogen-oxide analyzer (photo) allows the measurement of oxides of nitrogen (NOx) concentrations in raw exhaust of several thousand parts per million (ppm) down to a few parts per billion (ppb). This broad dynamic range combined with the linearity of the chemiluminescence principle meets the demands for response time, sensitivity and reproducibility. The instrument not only handles rough samples, such as hot and humid exhaust gas, but also diluted samples from bags. The entire unit, together with vacuum pump and ozone scrubber, fits in a single, compact case. — *Eco Physics AG, Duernten, Switzerland*
www.ecophysics.com



Eco Physics

This ULT freezer even sends Email alerts

A new range of ultra-low temperature (ULT) freezers (–86°C), tradenamed EvoSave-series, features a Web interface and unique TCP/IP address. In case of an alarm, the freezer will send an Email. Users simply connect the freezer to a local network, which activates the onboard Webmail server with recipients and the mail server will do the rest. This service offers maximum remote security, at no additional cost, says the manufacturer. Hall 4.2, Stand N62 — *Snijders Scientific B.V., Tilburg, The Netherlands*
www.snijders-scientific.com

This decanter centrifuge may be the largest of its kind

With the introduction of the new decanter centrifuge Z8E (photo, p. 32I-15), this company enlarges the capacity range of its decanters for the food and chemical industries. The Z8E is said to be the largest three-phase decanter with an adjustable impeller on the market. With the adjustable impeller, the fluctuations in the feed can be evened out automatically while the machine is running. At the same time, the fluid level in the decanter can be optimally readjusted. Thanks to its modular design, this decanter can be customized to the specific demands of each industry. Besides models for strict hygienic requirements of the food industry, there are more designs

Flottweg

in progress. For the chemical industry, gas-tight machines with ATEX certified equipment are currently being developed. The Z8E is available in two-phase as well as three-phase versions. Hall 5.0, Stand A86 — *Flottweg SE, Vilsbiburg, Germany*
www.flottweg.com

Photometers for a variety of applications

This company manufactures optical measuring devices for monitoring the quality of a large range of process variables in many different industries, including water, chemical, air and beverages. The company's photometers meet the highest standards of quality and reliability, and are used to support process optimization, and continuous safety, purity and quality control. Among the applications in which the photometers are used are for measuring turbidity, dissolved substances, color, oil or particulate matter. Hall 11.1, Stand A4 — *Sigrist-Photometer AG, Ennetbürgen, Switzerland*
www.photometer.com

A Web-based platform for assuring REACH compliance

Launched earlier this year, REACH Factory is said to be the first IT solution covering all aspects of the REACH (Registration, Evaluation and Authorization of Chemicals) regulation. REACH Factory is a Web platform made of six different tools that can be used individually or combined with one another for complete compliance. Developed by experts in chemistry, toxicology and IT, each tool meets one aspect of REACH and easily integrates into all information systems. Three tools allow data management in the supply chain, and three others help manage data within the company. Hall 9.2, Stand D39 — *EcoMundo, Issy-les-Moulineaux, France*
www.ecomundo.eu

Safely ground piping with this earthing bridge

The patented Earthing Bridge is now complemented with a new model — the Universal Earthing Bridge. The new version replaces the earthing cable traditionally used for electrostatic grounding of pipe systems. The bridge is fixed to the company's pull-ring using a simple screw, so no welding work is required, even for retrofitting exist-

Malvern Instruments

Fr. Jacob Söhne

ing systems. Other products (photo, p. 32I-16) highlighted at this company's stand is the new Hygiene Distributor, which is used in applications where frequent cleaning of the inner surfaces of pipes necessitates quick and easy disassembly and reassembly of the parts. The design of the distributor enables this to be achieved, even in its installed state. The entire shaft and flap components can be removed and refitted without the use of any tools. Hall 6.0, Stand B29 — *Fr. Jacob Söhne GmbH & Co. KG, Porta Westfalica, Germany*
www.jacob-rohre.de

Particle analysis from R&D to product quality control

This stand will present the complete range of complementary materials-characterization technologies and instruments, including the Morphologi G3 and Zetasizer Nano particle characterization systems (photo). This company has also recently announced a cooperation with Postnova Analytics (Landsberg, Germany) to deliver the combined FFF (field-flow-fractionation) and DLS (dynamic light scattering) solutions that provide critical insight when characterizing a number of challenging particulate systems. Such systems include complex, aggregated, cross-linked, nano-particles and fibrillated proteins. FFF enables the separation of particles that are too large for analysis by GPC/SEC, and the addition of this company's Zetasizer Nano as a DLS detector allows the subsequent measurement of absolute particle size. Hall 4.1, Stand D59 — *Malvern Instruments Ltd., Malvern, U.K.*
www.malvern.com

A large rotary vacuum filter for solid-liquid separation

The vacuum rotary drum filter features a scraper blade for continuous service, and 25 or 30 m^2 of filtration area. The drum (3-m dia., 2.7-m length) is subdivided into different sectors having air tubes connected to an extraction valve. These sectors are separated by specially formed pieces of AISAI 304, which support the drainage grills and the filters. The drum rotates with variable speed from 0.2 to 1.2 turns per minute. — *Velo Acciai Srl., Treviso, Italy*
www.veloacciai.com ■

Gerald Ondrey

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Tubing for Peristaltic Dosing Pumps

Peristaltic pumps work by compressing a tube against a circular pump housing with rollers on a rotating arm. The fluid that is ahead of the roller gets pushed forward, while new fluid is drawn into the tube by the vacuum generated as the tube returns to its relaxed state. Peristaltic pumps are a type of positive displacement pump that can be used in industrial chemical dosing applications and others, including medical applications. The tubing used to convey the material into and out of the pump mechanism is a critical aspect of pump performance. The following are considerations for selecting tubing materials for use with a peristaltic pump.

ADVANTAGES AND DISADVANTAGES OF PERISTALTIC PUMPS

Advantages	Disadvantages
• Dosing accuracy is high, and is not affected by line pressure and fluid viscosity	• Flexible tubing tends to degrade with time and requires periodic replacement
• Maintenance can be minimal due to the absence of valves, seals, pipework, strainers and so on	• The flow is pulsed, particularly at low rotational speeds, so peristaltic pumps are less suitable where a smooth, consistent flow is required
• Contamination is virtually eliminated because the only part of the pump in contact with the fluid being pumped is the interior of the tube	• Not as effective for continuous process duties, as opposed to intermittent duties, because hose and coolant replacements are needed
• Handling slurries, highly viscous, shear-sensitive and aggressive fluids is possible	• Largest sizes are limited to 10–15 gal/min
• Pump design prevents backflow and syphoning without valves	

Advantages and disadvantages

As dosing pumps, peristaltic-based systems have a number of advantages, along with some limitations (Table). Reducing the risk of contamination by pump components is a distinct advantage of peristaltic pumps, but the flow is non-uniform, which can present problems in certain applications requiring continuous flow.

Tubing materials

Peristaltic pump tubing is a key component, and needs to be selected thoughtfully. Major considerations for tubing are chemical compatibility, elastomeric performance and tube life.

Tubing for peristaltic pumps needs to be constructed of an elastomeric material in order to maintain the circular cross-sectional shape, even after millions of squeeze-cycles inside the pump. Because of this requirement, many non-elastomeric polymer materials that are effective at resisting chemical attack must be eliminated from consideration in these applications. Materials such as PTFE (polytetrafluoroethylene), polyolefins, PVDF (polyvinylidene fluoride) and so on should not be considered as material for pump tubing unless they are used as a lining of another tubing material.

Popular elastomers for pump tubing are silicone, PVC (polyvinyl chloride), EPDM (ethylene propylene diene monomer)+polypropylene (as in Santoprene), polyurethane and Neoprene. Of these materials, the EPDM+polypropylene ("-prenes") have the best fatigue resistance and a wide range of chemical compatibility. Silicone is popular with water-based fluids, such as in the biopharma industry, but have limited range of chemical compatibility in other industries.

To help select tubing materials, many tubing suppliers provide chemical compatibility charts, but it is important for engineers to use a chart designed specifically for pump tubing rather than for general use. Tubing that gets an acceptable rating for general contact with a given chemical might not withstand exposure to the same chemical when subjected to the physical stresses of peristaltic pumping.

When using compatibility charts, end-users should check the compatibility of each component of the solution, rather than just the main ingredient. Even trace levels of some acids or solvents can be enough to destroy pumps with exposure over longer periods of time.

Chemical resistance decreases as temperature increases. Chemicals that have no effect on the tubing material at room temperature could attack the tubing at elevated temperatures.

Immersion test

If information on chemical compatibility cannot be found, or if a plant's operating conditions are significantly different from those used to determine the chemical-resistance ratings, an immersion test can be performed. In an immersion test, a small length of tubing is weighed accurately, and its diameter and length measured. The tubing is then immersed in a closed vessel containing the chemical in question for 48 h. The test piece is then rinsed, dried, weighed and measured again, and changes are recorded. The tubing should also be examined for signs of softening or embrittlement, which would indicate chemical attack on the tubing.

Tube squeezing

The amount of squeeze applied to the tubing affects pumping performance and the tube life — more squeezing decreases the tubing life dramatically, while less squeezing decreases the pumping efficiency, especially in high-pressure pumping.

Thicker-walled tubes generate greater suction when they return to their original shape after being squeezed, so they are generally better for pumping more viscous fluids. For longer tube life, larger-bore tubes at lower pumping speeds should be used.

Pressure capabilities

Peristaltic pump applications are typically limited by the pressure capabilities of the tubing. Typical pump tubing materials have working pressure ratings from 10 to 40 psi, with softer materials such as silicone at the low end and firmer materials at the higher end. Recent material advances are expanding the pressure ranges for peristaltic pump applications.

Pressure sources in a fluid-handling system can vary. Backpressure can be generated by the fluid passing through a filter or by the fluid pushing through the flowmeters or the valves. Backpressure can also come from the fluid pumping into a pressurized reaction vessel.

Peristaltic pumps deliver fixed amounts of fluid with each pass of a roller over the tube, so the size of the tube has a direct effect on the amount of fluid delivered. Variations in tubing dimensions can mean compromised consistency and repeatability, so a tighter tubing-dimension tolerance is better.

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Water-Saving Strategies for the CPI

Water savings at CPI facilities depend on effective water management, smart application of technology and corporate support

Y.A. Liu
Virginia Polytechnic Institute and State University

TABLE 1. A COMPARISON OF TYPICAL WATER QUALITIES OF WASTEWATER TREATMENT PLANT (WWTP) EFFLUENT AND COOLING TOWER MAKEUP WATER

Water quality	WWTP effluent	Cooling tower makeup water
Hardness ($CaCO_3$), mg/L	40 to 65	25.5
Alkalinity ($CaCO_3$), mg/L	20 to 160	23.2
Cl^-, mg/L	70 to 200	10.0
SO_4^{2-}, mg/L	45 to 390	15.0
Chemical O_2 demand (COD), mg/L	65 to 75 (COD_{Cr})	1.0 (COD_{Mn})
Suspended solids, mg/L	71.0	1.0
Oil, mg/L	1.5	0.0
NH_3-N, mg/L	2 to 15	0.1
pH	6.5 to 7.8	6.6
Bacteria, No./mL	1.6×10^5	1.6×10^2

Reducing freshwater consumption and wastewater discharge at large petroleum-refining and chemical-production facilities can lower costs, while allowing plants to expand production capacities without having to secure additional freshwater resources and without having to enlarge their wastewater treatment plants. The key approaches to saving significant amounts of water are: improved water management, implementing process changes that maximize water reuse and minimize wastewater generation; and a corporate-wide focus on the "Four-Rs" — regeneration, recycling, reuse and replacement.

This article describes the methodology used in several water-saving projects led by the author at large chemical and petroleum refining facilities in the Asia-Pacific region, as well as proven water-saving technologies implemented. In addition to improved water management and better use of water-saving technology, the ultimate success of water-saving projects at these large facilities depends on strong support from senior-level corporate executives and production managers, corporate-wide training of project teams and a broad effort to promote corporate-wide enthusiasm for water savings.

PROJECT METHODOLOGY

The following describes the methodology used in the water-saving projects discussed in the article.

Step 1. Secure executive and management support, and organize water-saving project teams. The active participation of executive and production leaders in both the company headquarters and subsidiary facility sites was a key factor to ensuring the success of the project.

Step 2. Offer corporate-wide water-saving training courses. The project started with a series of week-long training courses for project engineers from 46 Sinopec subsidiaries. The courses had the following goals: 1) to teach system engineering tools and environmental engineering know-how for water savings; 2) to introduce effective technologies for the four Rs in water savings (regeneration, recycle, reuse and replacement); 3) to share industrial success stories of water reuse and wastewater minimization; and 4) to develop the enthusiasm for water savings throughout Sinopec subsidiaries.

Step 3. Perform onsite visits to refining and chemical subsidiaries to identify the best practice and technology needs for water savings, to share industrial success stories, and to develop enthusiasm for water savings. The project team made three extensive trips and traveled more than 37,000 miles to all of Sinopec's 46 refining and chemical subsidiaries during 2004–2005 for onsite reviews of the current situation of water usage and wastewater treatment and discharge. During this period, we also made a site visit to FPG's refinery and ethylene plants.

Step 4. Develop water-balance diagrams, a water-reuse proposal and investment estimate for each refining and chemical subsidiary. While working with visiting engineers from FPG at Virginia Tech in the spring of 2004, the project team developed the methodology for representing a water-balance diagram (Figure 2), an Excel-spreadsheet-based accounting of current water use and wastewater generation. Each water-balance diagram lists all of the water sources entering each water-using process. These include, for example, high-pressure (HP) steam, medium-pressure (MP) steam, low-pressure (LP) steam, chemical treated water for utility boilers, industrial water (freshwater), steam condensate, and so on. For each water-using process, the diagram shows all of its inlet water streams, outlet water streams, and water gains and

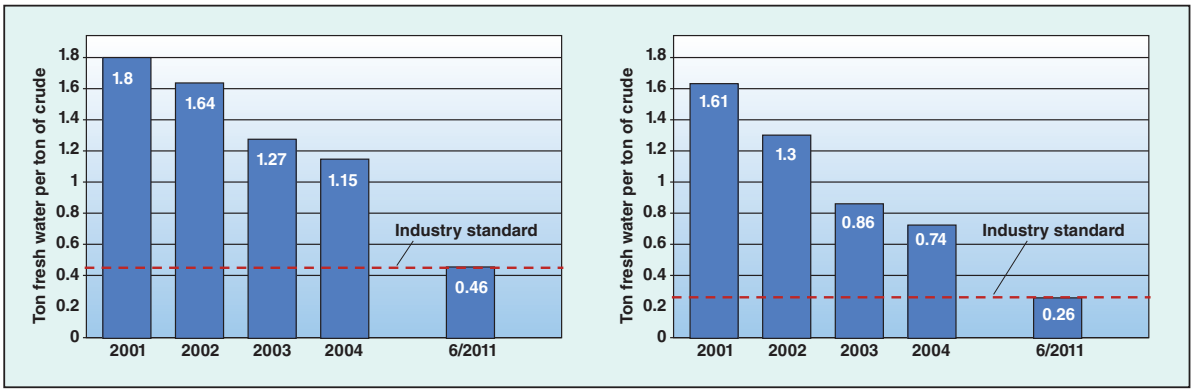

FIGURE 1. (left) Sinopec's refinery freshwater consumption drops below the top industrial standard of 0.5 ton freshwater per ton of crude oil refined; (right) Sinopec's refinery wastewater discharge continues to approach the top industrial standard of 0.2 ton wastewater per ton of crude oil refined

WATER-SAVING PROJECTS

During a sabbatical leave from Virginia Tech in 2004–2005, the author led a project team tasked with developing water-saving engineering and investment proposals for 46 refining and chemical subsidiaries of China Petroleum and Chemical Corp. (Sinopec), the largest energy and chemical company in Asia and a global top-three chemical company [*1*]. The result of the project team's work was an investment of $284 million over three years from 2005 to 2008 to implement the proposals. The project methodology is discussed further in the box on p. 34–35.

The data in Figure 1 show the freshwater consumption and wastewater discharge per ton of crude oil refined at Sinopec refineries before and after the project. For each ton of crude oil refined, freshwater consumption dropped from 1.8 ton in 2004 to 0.46 ton in mid-2011, while wastewater discharge volume decreased from 1.61 ton in 2004 to 0.26 ton. This result represents a 60% drop in freshwater consumption and a 65% drop in wastewater discharge since 2004. The current freshwater consumption and wastewater dischage levels also exceed or approach the top industrial standard of 0.5 ton freshwater consumed per ton of crude oil refined, and 0.2 ton wastewater discharged [*2*]. The project has generated similar reductions of freshwater consumption and waster discharge at SINOPEC's chemical subsidiaries. In addition, between 2004 and 2008, the author advised engineers at Formosa Plastics Group (FPG; Taiwan; www.fpg.com.tw), a global top-seven chemical company, on the development of water-saving proposals at FPG's refinery and ethylene plants at Mailiao, Taiwan.

In the course of the water-saving projects discussed here, the project teams made some significant improvements to the system engineering tools used, as well as in the environmental engineering know-how and water-saving project strategy that was originally presented in the author's previous textbook [*3*] and article [*4*].

losses. The diagram also includes the wastewater treatment plant (WWTP). For each water-balance diagram, the team gathered the essential water-quality data on water sources and demands for each water-using process, as well as those of the inlet and effluent streams of the WWTP.

To reduce freshwater consumption and wastewater discharge, all outlet water streams from each water-using process should be considered as potential water sources. If necessary, these streams go through some mild or deep treatment to meet the water-quality requirements of some downstream water-using processes [*2*].

The management of each Sinopec subsidiary paid close attention to the water-saving project. In one case, a plant manager's office at a large refinery had a water-balance diagram posted on his office wall. For two months, the manager met every afternoon with project teams to track the progress of water-reuse and wastewater minimization projects. Upon completion the project, this refinery was able to reduce its freshwater consumption to less than 0.35 ton of water per ton of crude oil refined, which is well below the top industrial standard of 0.5 ton per ton of crude oil refined.

Step 5. Develop engineering designs and investment feasibility studies for proposed measures, and schedule expert panel reviews for proposal improvement.

Step 6. Develop project execution manuals, and seek approval from the corporate president and board chairman. The project team devoted a substantial amount of time to organizing the project execution manual under each management department, such as refining and chemical business units, safety and environment department, R&D department, and development and planning department and others. For each department, we listed the specific R&D tasks, water-reuse proposals, amount of water saved (ton/h), total investment required, investment per ton of water saved and total number of projects.

Step 7. Hold a corporate-wide water-saving conference to promote project implementation. On July 18, 2005, Sinopec held its first ever corporate-wide water-saving conference. During the conference, the board chairman gave specific instructions for department heads at corporate headquarters and presidents of refining and chemical subsidiaries to implement the water-saving proposals to complete the project within three years, along with specific rewards and penalty guidelines. The board chairman emphasized the project urgency, as well as the corporate environmental stewardship and social responsibility in reducing freshwater consumption and wastewater discharge. This high level of attention devoted by the board chairman has ensured the project success. ❑

TECHNOLOGY KNOW-HOW

The most important strategies for reducing water consumption and wastewater discharge in large refining and chemical companies can be categorized as follows: 1) better water management; 2) process change and integration; and (3) regeneration, recycle, reuse and replacement (the four Rs). By focusing on the practical aspects of managing water use, applying proven technologies, and fostering corporate buy-in, plants can significantly cut down water use and wastewater discharge. Readers should check Ref. [5] for further technology details.

Improved water management

The success of any water-saving project depends to the greatest extent on effective and efficient water management, and less on water-saving technology. In fact, the experience of the project teams suggests that 70% of the success of a water-saving project derives from management improvement, and only 30% comes from applications of water-saving technology. In particular, much of the unaccounted water loss revealed by water-balance diagrams (which list water inputs and outputs) and monthly water auditing of a chemical plant results from leakage from underground water pipelines. For example, in one ethylene plant, we observed underground water leakage as high as 100 ton/h. It is essential to regularly use a modern pipeline leak detection system, and electronic listening and leak detection devices to identify water leakage and repair failing water pipelines.

Improving water management requires an accurate monthly auditing of water consumption for each manufacturing plant. So for each refinery, the project team compiled a monthly accounting spreadsheet that included the following information:

- Crude oil refined (ton/mo.)
- Total freshwater (industrial water) consumed (ton/mo.)
- Freshwater consumed per ton of crude oil refined (tons)
- Wastewater discharged per ton of crude oil refined (tons)
- Freshwater reuse percentage
- Concentration ratio of cooling-tower recirculating water
- Freshwater consumption for the following: cooling tower makeup water; for producing high-purity boiler makeup water (chemically treated water); the freshwater equivalent of externally purchased steam; freshwater to processing units; water

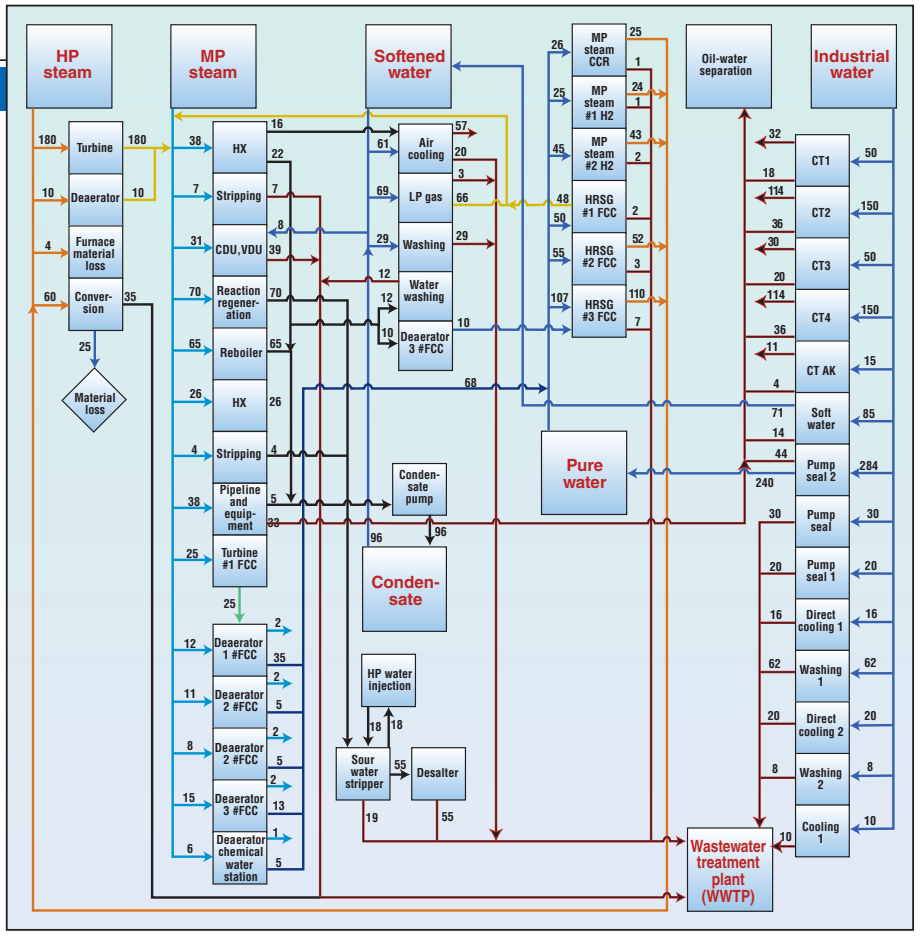

FIGURE 2. An example of a water-balance diagram for a refinery

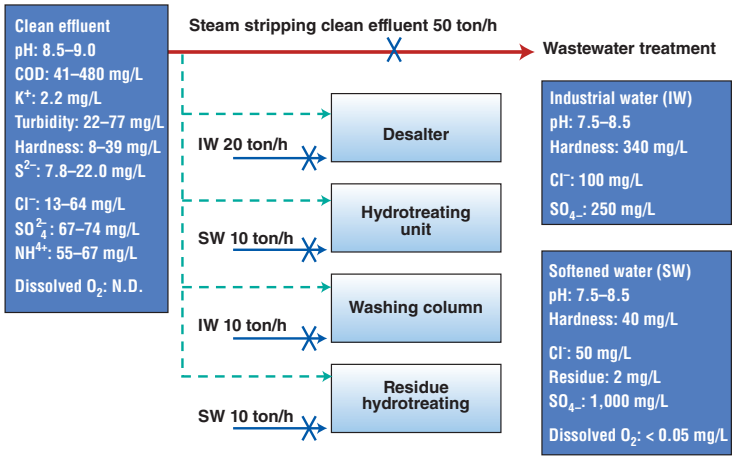

FIGURE 3. Clean effluent from the steam stripping of sour water can be used as makeup water for desalters, quench towers, washing columns, hyrdotreating units and others

All photos: SINOPEC

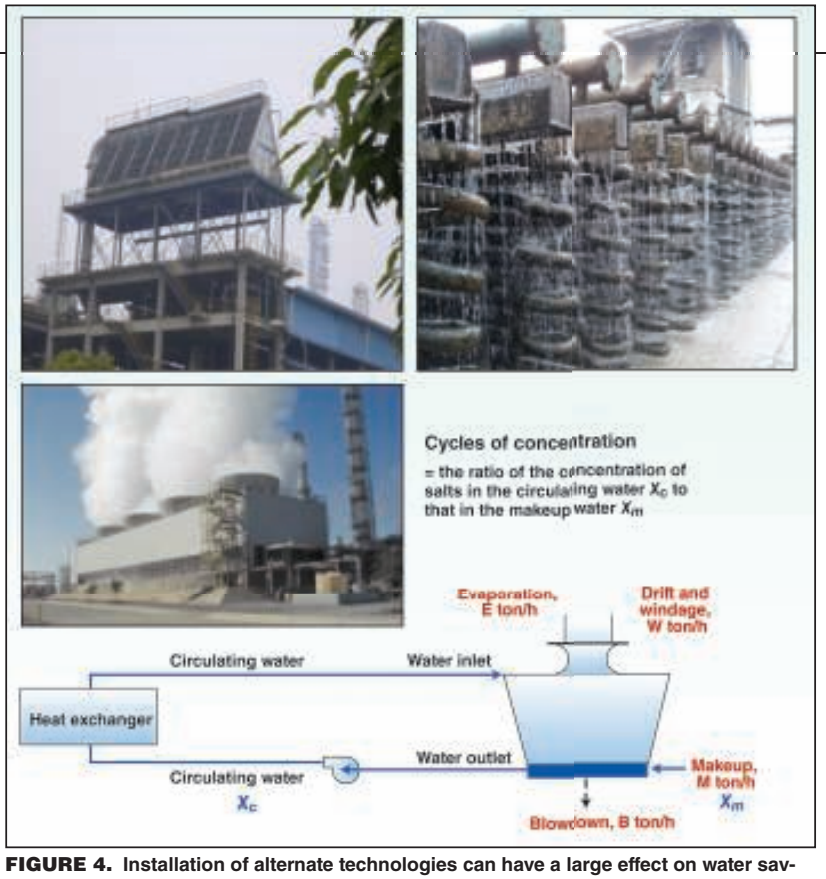

FIGURE 4. Installation of alternate technologies can have a large effect on water savings. Examples include replacing water cooling with air cooling in a hydrocracking system (top left); a once-through water cooling can be replaced by a closed recirculating cooling system (top right); a closed recirculating cooling system routed though a cooling tower (bottom)

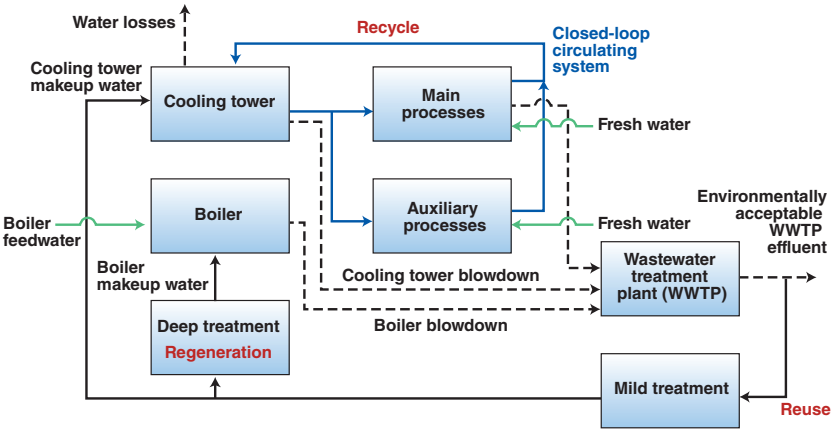

FIGURE 5. Water savings opportunities expand through additional treatment of environmentally acceptable WWTP effluent. The additional treatment allows WWTP effluent to be used as cooling-tower makeup water (mild treatment), or as boiler makeup water (deep treatment)

leakage and loss, and others
- Water reused (tons), in the following categories: steam condensate reused, amount of wastewater treatment plant (WWTP) effluent reused after further treatment
- Corrosion monitoring, including test-tube corrosion rate in mm/yr and adhesion rate in mg/(cm^2) per month.

With this monthly accounting available, financial and personnel resouces can be directed at areas most ripe for improvement, while the best-performing areas are replicated.

Process changes

Effective process changes can maximize water reuse and minimize wastewater generation in existing chemical plants [3]. And intelligently integrating the use of materials and energy through process integration can optimize water and energy savings. The following items are examples of process changes implemented as a result of the project team's efforts that had a positive impact on water savings.

Hot-material feed and heat integration. Hot product streams from upstream process units are sent to downstream process units directly as feeds, without entering intermediate storage tanks or undergoing water cooling or feed preheating [6].

For example, in one refinery, products from the crude distillation unit (CDU) include naphtha, diesel, vacuum wax oil and vacuum residue. The gas oils to the fluid catalytic cracking (FCC) unit come from atmospheric and vacuum distillation, delayed coking and solvent de-asphalting units. The liquefied gas product from the FCC goes to the gas fractionation unit, while the gasoline and diesel products from the FCC unit are sent to the hydrotreating unit. The delayed-coking unit processes the residue from the CDU, and sends its gasoline and diesel products to the hydrotreating unit. The solvent de-asphalting unit processes the residue from the CDU, and sends its product oil to the FCC and fertilizer plant. By raising the outlet temperatures of several product streams that serve as feed streams to downstream processing units, uncessary water-cooling or feed-preheating can be avoided, thus lowering energy costs and recirculating cooling-water flowrates.

Raising storage temperatures. Another example of a successful process change is raising the storage temperature of selected products. Temperatures must still be below their safe-storage temperatures, but raising storage temperatures helps avoid the need for water cooling.

Recovery of low-temperature heat sources. Recovering low-temperature heat sources can also realize water-

savings. For example, the overhead of the FCC-gas fractionation unit can be used as a heat source to heat the recirculating desalted water, which is then used as the heat source for the low-temperature depropanizer and propylene purification units.

Heat integration. Another technique for water savings is to integrate the heat from low-temperature streams, such as steam condensate and desalted water. For example, in Sinopec's largest system, which recovers 1,120 ton/h of steam condensate, the project team implemented a change whereby the condensate is cooled to its purification temperature of 50°C by heating up the desalted water and other low-temperature streams.

Reuse of clean effluent. Water can be saved by reusing the clean effluent from steam stripping as makeup water streams flowing to the desalter, the quench tower, the washing column, the hydrotreating unit and others. The clean effluent from steam stripping of sour water is a quality water source that can replace industrial water (freshwater) for several process units. Clean effluent is also a good source of injection water for hydrotreating columns. Figure 3 illustrates this application, in which the qualities of the clean effluent are acceptable when compared to those of industrial water and injection water. Throughout our project, the team used the same approach as shown in Figure 3 to present our water-reuse proposal, in which we compared the available flowrates and qualities of both the water source and water demands for each reuse proposal. The engineering and economic evaluation specialists on our project team helped the facilities estimate the investment cost and payback period for each water-reuse proposal.

THE FOUR "R"S

Water saving initiatives involve a careful focus on regeneration, recycling, reuse and replacement.

Replacement refers to a change from one system within a process to an alternative that allows water savings to be realized. An example can be found in Figure 4, which illustrates an air cooler that replaces a water cooler in a hydrocracking system. Figure 5 also shows the once-through water cooling that an old chemical subsidiary was practicing for years, taking advantage of the water from the Yangtze River. Finally Figure 4 shows a closed recirculating cooling system, which also illustrates the definition of cycle of concentration of a cooling tower. By replacing the once-through water cooling with a closed recirculating cooling system throughout this chemical subsidiary, its yearly freshwater consumption dropped from 1.4 to 0.49 million tons, representing a 65% reduction [7].

TABLE 2. WATER QUALITIES AFTER ULTRAFILTRATION TREATMENT

	Tianjin	Jinan	Wuhan	Maoming	Cooling tower makeup water
pH	7.9	7.2	8.4	~6.0–9.0	~6.5–9.0
COD_{Cr}(mg/L)	51	38	55	52	≤60
Oil, mg/L	0.75	0.80	0.86	1.5	≤2
NH_3-N, mg/L	0.2	0.86	2.9	5.6	≤10
Turbidity, NTU	0.03	0.23	0.12	0.2	≤10
SO_4^{2-}, mg/L	190	230	202	74.2	≤300
Hardness, $CaCO_3$, mg/L	150	65	88	62.2	~50–300
Alkalinity, mg/L	170	50	360	39.7	~50–300
Conductivity, μS/cm	2,640	2,270	1,150	972	≤1,200

TABLE 3. WATER QUALITIES AFTER REVERSE OSMOSIS TREATMENT

	Tianjin, RO effluent	Tianjin cooling tower makeup water	Jinan, RO effluent	Jinan cooling tower makeup water
pH	5.75	7.93	6.33	7.6
Oil, mg/L	0.41	–	0.66	
NH_3-N, mg/L	N.D.	–	N.D	<0.02
Turbidity, NTU	N.D	0.43	N.D	
Hardness, $CaCO_3$ mg/L	N.D	94	N.D	38.3
Cl^-, mg/L	11.2	53	6.1	
Iron, mg/L	N.D.	0.13	0.15	180
Alkalinity, mg/L	5.5	117	5.5	450
Conductivity, μS/cm	65	576	50	295

WWTP effluent reuse, regeneration and recycling

In refining and chemical plants, cooling-tower makeup water and boiler makeup water represent two of the significant freshwater users with specific water-quality constraints. Significant water savings can result through additional mild treatment of the environmentally acceptable wastewater treatment plant (WWTP) effluent as cooling tower makeup water, or through further deep treatment as boiler makeup water (desalted water) (Figure 5).

Mild treatment. One approach to additional mild treatment of WWTP effluent is aimed at using it as cooling-tower makeup water. Mild treatment of the WWTP effluent will make its water qualities comparable to those acceptable as cooling-tower makeup water. Table 1 shows a typical comparison.

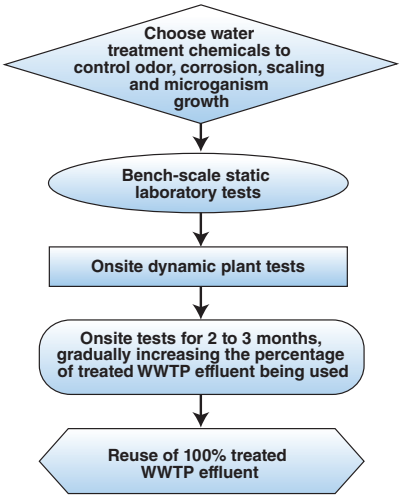

FIGURE 6. Implementation of a mild treatment scheme for WWTP effluent can allow its use as cooling-tower makeup water

Our project applied the technology developed by the Water Treatment Center of Sinopec's Research Institute of Petroleum Processing (RIPP) in Beijing for mild treatment of the WWTP effluent. The technology combines physical, biological, and chemical

FIGURE 7. Photos from a large ethylene plant illustrate how treated WWTP effluent can be reused as cooling-tower makeup water

treatments for improving WWTP effluent qualities and for control of odor, corrosion, scaling and bacteria growth. This technology involves the following steps: secondary water treatment, biological treatment, oxidation, filtration, and stabilization of water qualities.

Stabilization of water qualities involves the addition of water treatment additives, particularly scale and corrosion inhibitors, such as organic phosphate, to slow down scaling and corrosion, as well as oxidizing biocides (isothiazolin ketone, for example) to control the propagation of microorganisms, and biological sludge removal and cleaning agents to strip-clean biological fouling.

Figure 6 illustrates the procedure to gradually replace the freshwater by the mildly treated WWTP effluent as cooling-tower makeup water.

Figure 7 shows a cooling tower system serving a 1-million ton/yr ethylene plant, and illustrates some components of the mild treatment facility for reusing 1,000 ton/h of WWTP effluent as cooling-tower makeup water. This reuse dropped the freshwater consumption per ton of ethylene produced by 40%, while reducing the wastewater discharge by 77%. The investment cost for the treatment facility was about $2 million with a payback time of 1.8 years, and the operating cost (including the cost of the wastewater treatment additives) of the facility is about $0.20 per ton of WWTP effluent treated.

Figure 8 illustrates the results of longterm monitoring of the corrosion and adhesion rates from 2003 to 2009 in a refinery processing 20 million ton/yr of crude oil that reuses 600 ton/h of the mildly treated WWTP effluent as cooling-tower makeup water. For each ton of crude oil refined, this refining subsidiary currently consumes 0.285 ton of freshwater, while discharging 0.056 ton of wastewater, representing one of the best performances of the Sinopec refineries.

Beginning in 2005, our project team has proactively pushed for reusing the mildly treated WWTP effluent as cooling-tower makeup water in petroleum refineries and ethylene plants. As of late 2011, 35 refineries and five ethylene plants have implemented this approach, with a total reuse capacity of 120,000 ton/d. The largest facility has a capacity of 24,000 ton/d. This water reuse has enabled the cooling towers to run at a minimum concentration ratio of four to six, while keeping the corrosion rate below 0.075 mm/yr, the cohesion rate below 15 mg/cm^2 per month, and the total number of bacteria below 1×10^5 per mL.

Deep treatment. More thorough, deep treatment of WWTP effluent using ultrafiltration (UF) and reverse osmosis (RO) can allow its use as cooling-tower makeup water or as boiler makeup water.

One of the early successful applications of UF and RO for the deep treatment of 800 ton/h of refinery WWTP effluent as boiler makeup water occurred at Sinopec's Yanshan Refinery in Beijing [8]. A membrane filtration spectrum diagram can be used to display the salts and other contaminants that UF and RO technologies can separate from wastewater, together with the size ranges for various membrane applications [9].

The keys to any successful applications of membrane filtration to wastewater regeneration and reuse are feedwater pretreatment and onsite membrane experiments. In 2005, our project team launched a comprehensive 100-day testing program that involved over 60 engineers and scien-

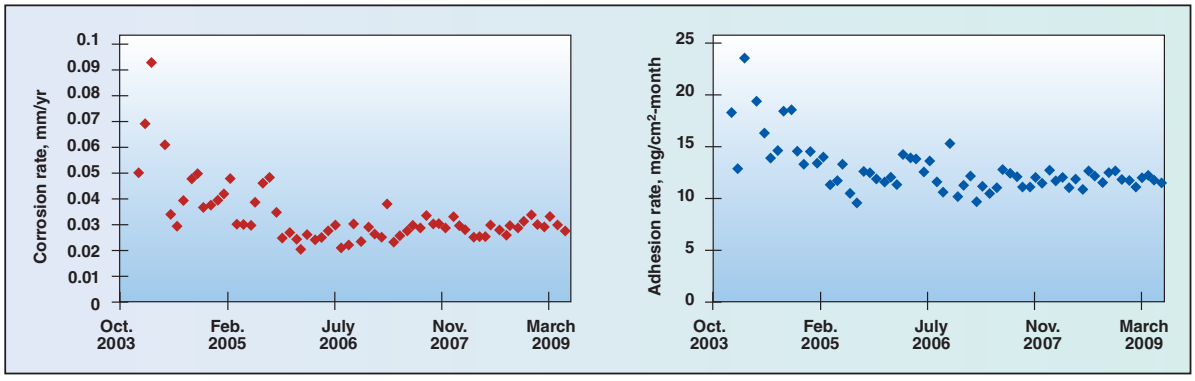

FIGURE 8. The project team monitored corrosion rate (left; mm/year) and adhesion rate (right; mg/cm^2 per month) when reusing treated WWTP as makeup water to the cooling tower of a large refinery

tists from the membrane vendors, as well as the Environment Institute of the Sinopec Beijing Research Institute of Chemical Industries (BRICI).

The goals of the testing program were threefold: (1) to investigate the effects of wastewater qualities on the membrane performance and selection; (2) to quantify the performance of both feedwater pretreatment and membrane filtration, and identify the optimum membrane design parameters and operational conditions; and (3) to characterize the membrane fouling and cleaning cycle, including the cleaning liquid formulation, cleaning procedure, and control indicator and method. Figure 9 illustrates the membrane testing procedure. Our testing program considered water qualities from four representative regions of Sinopec's refining and chemical subsidiaries, and chose the appropriate feedwater pretreatment and membrane filtration scheme for each region.

Tables 2 and 3 list the water qualities after UF and RO treatment of the WWTP effluent together with the desired water quality for cooling-tower makeup water. Two observations are evident. First, not all of the WWTP effluents require RO treatment to reach acceptable qualities for reuse as cooling-tower makeup water. Second, the water qualities after both UF and RO treatment are typically of sufficient quality for use as cooling-tower makeup water or boiler makeup water (desalted water).

The key results from this feedwater pretreatment and membrane experiment program were as follows: 1) sand filtration and aerated biological filtration are effective pretreatment schemes; 2) water recoveries for UF is above 84% and for RO is above 70%, salt removal by RO is above 97%, and typical membrane fluxes for UF are 40 to 75 L/m^2·h, and for RO are 20 to 25 L/m^2·h; 3) chemical washing for both UF and RO membranes takes place once every two to three months; 4) UF membranes can last for five years, and RO membranes need replacement after two years; and 5) the operating cost for feedwater pretreatment and UF-RO membrane filtration is about $0.50/ton of clean water recovered, and the operating cost for feed pretreatment and UF membrane filtration is about $0.15/ton of clean water recovered.

With these onsite testing results and experiences, our project team was able to apply UF and RO for deep treatment of WWTP effluents for reuse as cooling-tower makeup water, or as boiler makeup water in over 20 subsidiaries. With an increasing number of UF and RO applications, their unit investment cost has continued to drop in recent years.

Our project has also applied the technology of membrane biological reactors (MBRs) that combine membrane filtration for salt removal with biological wastewater treatment in several petroleum refining and chemical plants.

To further minimize the wastewater discharge, our project team continues to investigate the use of multi-effect membrane distillation and other approaches for treating and reusing the brine water rejected by RO.

In order to minimize water consumption and to approach zero-liquid discharge in chemical and biofuel plants, it is essential to apply the same water-saving practices as those used in the Sinopec project, particularly reusing the treated WWTP effluent as cooling-tower makeup water, or as boiler makeup water.

Steam condensate recovery

Steam condensate recovered from chemical processes, after some purification, can serve as makeup water to utility boilers. This water reuse technique generates cost savings in water resources and desalting operations, as well as energy recovery from steam condenstate.

In July 2010, one of Sinopec's refining and chemical subsidiaries started up its 1 million ton/yr ethylene plant. One project team member was in charge of the design of utility and wastewater treatment systems of this plant. Throughout her design, the project team member made a serious effort to incorporate all proven technologies that the project team had implemented throughout Sinopec's refining and chemical subsidiaries. This resulted in a final design that reuses 98.5% of the plant's water resources. Additionally, this plant has developed an efficient process to recover, purify and reuse 1,120 ton/h of steam condensate, which represents the largest condensate recovery system ever built in China.

Recovered condensate should meet the following key quality require-

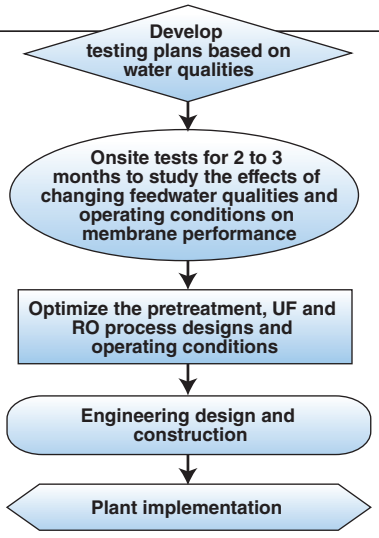

FIGURE 9. Onsite membrane testing is essential for recovery and reuse of deeply treated WWTP effluent as cooling-tower makeup water or boiler makeup water

ments: (1) suspended solids of less than 10 mg/L; and (2) total organic carbon (TOC) or oil content less than 10 mg/L. Prior to its final purification and reuse as boiler makeup water, the recovered condensate may need to undergo some pretreatment to remove oil, iron and other contaminants and to ensure that suspended solids are less than 1 mg/L and TOC or oil is less than 0.3 mg/L.

There are two alternative strategies for this condensate recovery and pretreatment. The first is applying heat integration to recover the condensate energy (for example, to use the high-tempertaure condensate to heat up the desalted water and other low-temperature process streams), and lower its temperature to approximately 50°C to enable a low-temperature recovery and pretreatment by conventional technologies. The second is applying the latest high-temperature recovery and pretreatment technology (≤85°C) without lowering the condensate temperature.

In a number of onsite testing programs at Sinopec's refining and chemical subsidiaries from September 2004 to October 2010, our project team concluded that for a condensate recovery capacity of approximately 300 ton/h, a high-temperature recovery and preatment technology that combines the active ceramic-molecular membrane ultrafiltration with the functional-group-activated carbon-fiber adsorption appears to be efficient and economical. At least nine Sinopec subsidiaries and 24 other petroleum refining and chemical plants in China have implemented this technology as of July 2011 [*10*].

Prior to last year, there had been no successful experience of applying this technology — at least within China — to a large-scale condensate recovery system with a capacity of over 1,100 ton/h. Additionally, in this particular ethylene plant, there is a great need for low-temperature heat sources to heat up some process streams. Thus, the final implementation of the condensate recovery system in this ethylene plant follows the following process scheme: process optimization and heat integration; followed by lowering of condensate temperature and heat recovery; then low-temperature recovery and pre-treatment. The final purification of the recovered condensate uses conventional activated-carbon filtration, followed by an ion-exchange operation.

CORPORATE SUPPORT

In addition to improved water management and application of new technologies, water-saving efforts in large petroleum refining and chemical companies depend on an environment of corporate support to be successful. The support should take the following forms: 1) strong support by senior executives and production managers; 2) company-wide training of project teams; and 3) serious promotion of corporate-wide enthusiasm for water savings.

Developing and implementing substantial water savings can allow large petroleum refining and chemical companies to expand production capacities without having to secure additional freshwater sources or enlarge their wastewater treatment facilities. For example, despite a significant increase in annual sales revenue from 2000 to 2011, a proactive, company-wide water-saving initiative at the Sinopec subsidiary in Yanshan actually dropped its freshwater consumption from 68 to 20.74 million ton/yr, while increasing wastewater regeneration, recycling and reuse to 7.4 million ton/yr. ■

Edited by Scott Jenkins

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Acknowledements

The author thanks Mr. Wang Jiming, Past President, Mr. Wang Tianpu, president, Mr. Cao Xianghong, past senior vice president and chief technology officer of Sinopec, and Mr. Wilfred Wang, past chairman of Formosa Petrochemical Corp., for their strong support of water-saving projects. The author also thanks Aspen Technology, Inc., Sinopec, Milliken Chemical, Alliant Techsystems, Novozymes Biological, and Mid-Atlantic Technology, Research and Innovation Center, for their support of the Center of Excellence in Process System Engineering at Virginia Tech.

Centrifugal Compressors for CPI Plants

Follow this guidance to improve selection, performance and reliability of centrifugal compressors

Amin Almasi
Rotating Machine Consultant

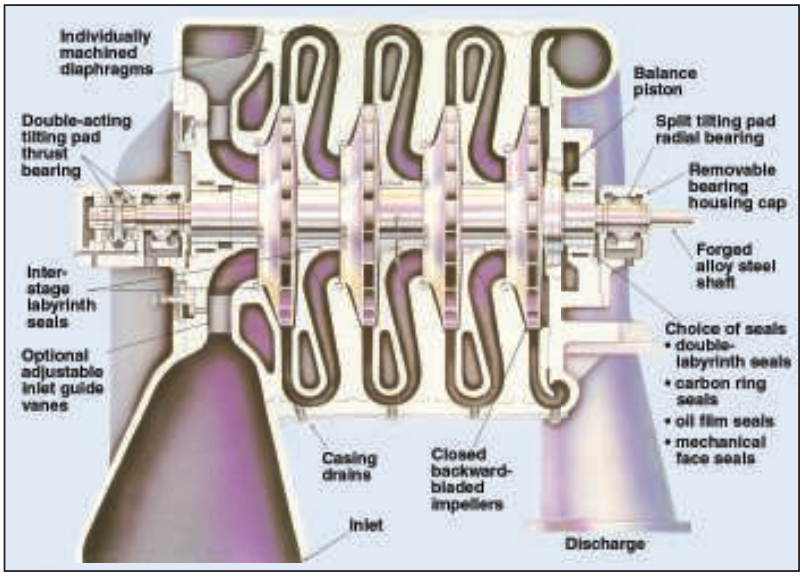

FIGURE 1. This cutaway diagram shows the internals of a process centrifugal compressor with a multi-impeller, between-bearing design

The growth in use of centrifugal compressors in chemical process industries (CPI) applications in recent decades has been brought about by four factors: 1) advances in dry gas seal technology; 2) modern aerodynamic, rotor-dynamic and thermodynamic knowledge and techniques; 3) advanced manufacturing methods to producing accurate rotating parts and various complex components with reasonable costs; and 4) the ability to simplify the control and anti-surge systems of a centrifugal compressor (and its driver) through the use of modern control and variable-speed technologies.

With these advances, and because of their simplicity, reliability, lightweight, and compact design, centrifugal compressors have become much more popular for use in CPI plants.

As CPI plant sizes increase, the pressure to improve reliability is very high because of the large economic impact of a nonscheduled shutdown. Today, the run time between centrifugal compressor overhauls is three to six years or more.

Centrifugal compressors

Figures 1 and 2 show examples of centrifugal compressors.

For low-pressure applications (say below 25–35 bars), the horizontally split-casing centrifugal compressor (Figure 2) is commonly employed. Maintenance of the horizontally split compressor is relatively simple compared to other designs. When the pressure is high (say above 40 bars) to maintain a proper joint seal or for low-molecular-weight gas services, another style commonly used is referred to as a barrel-type compressor (or vertically split type). For large machines, a vertically split casing is sometimes used for above around 25 bars, and for hydrogen-rich gas, even above 14 bars. In the multi-impeller configuration, the impeller-assembly is constructed with a removable, horizontally split inner barrel (known as a "bundle") that permits the removal of the rotor assembly without removing the impellers (removing rotor assembly as a single piece).

The single-stage centrifugal compressor can be arranged in an overhung style. The flow usually enters axially and exits in a tangential direction. Duties requiring one wheel (one impeller) are usually coped with by the use of a single overhung impeller. Often a step-up gear system, as a gear unit or as a part of compressor, is required. Overhung impellers are usually three-dimentional semi-open types, which are highly efficient. There is usually no need to accommodate a shaft in the eye of the impeller. It is, on very rare occasions, constructed in the multistage form, but an overhung machine has no more than two impellers. The overhung compressor is most often more competitively priced than the between-bearing compressor design. Careful applications must be made because the overhung impeller configuration is more sensitive to imbalance than the between-bearing designs. If impeller fouling is anticipated, the overhung design may not be acceptable. Some overhung compressors do not permit the removal of the rotor without first removing the impeller.

Compressor boosters, such as the one shown in Figure 3, are usually constructed with the axial inlet and outlet opposite each other in the horizontal plane. Sometimes it is with horizontal side nozzles (both suction and discharge).

Cast iron construction is used for low pressures, whereas cast steel is required when hazardous gases are handled. Vertically split (or barrel) casings, in cast steel, fabricated or

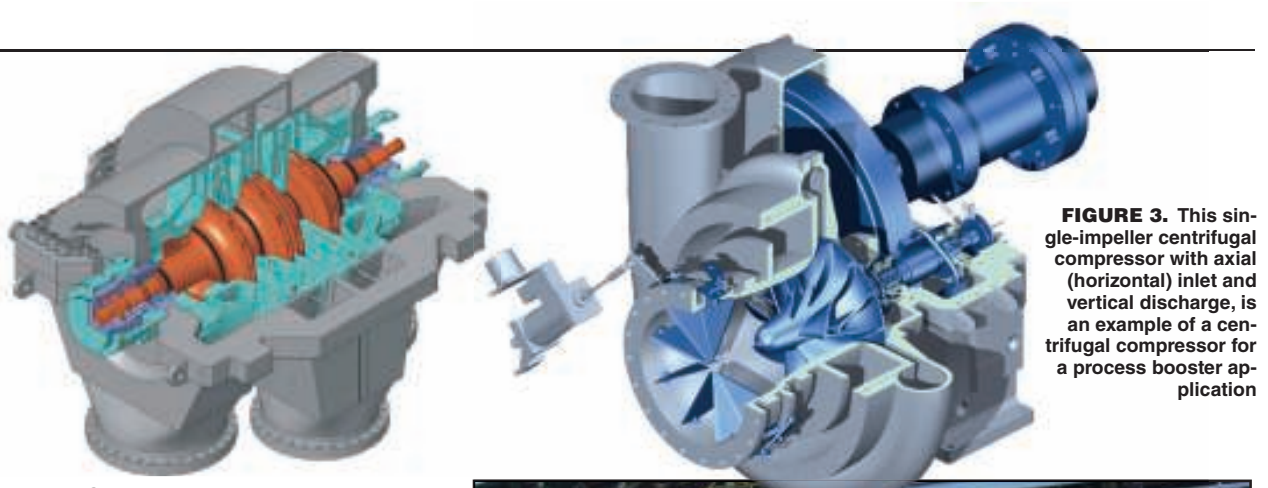

FIGURE 3. This single-impeller centrifugal compressor with axial (horizontal) inlet and vertical discharge, is an example of a centrifugal compressor for a process booster application

FIGURE 2. This cutaway diagram shows the internals of a horizontally split centrifugal compressor. With this horizontally split casing, major maintenance is simpler with downward piping connections, because there is no need to disturb the pipe-work when opening the casing

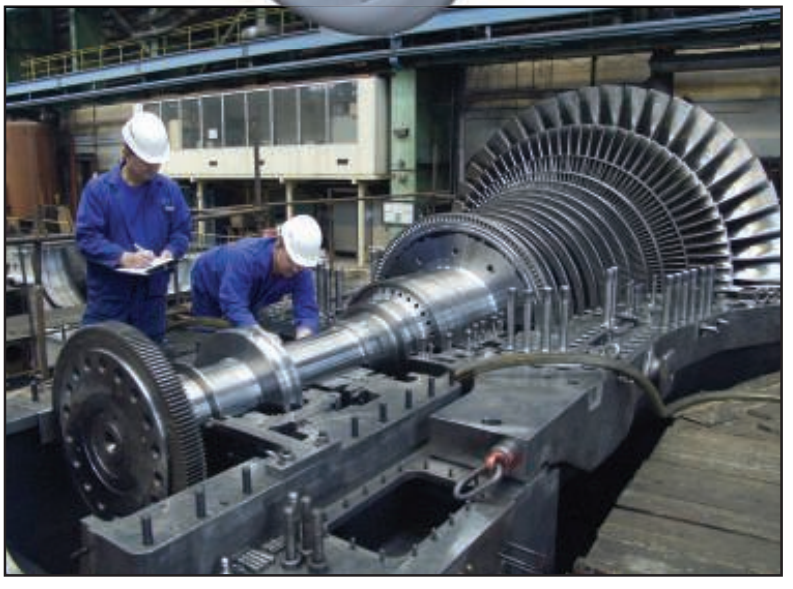

FIGURE 4. The steam turbine driver shown here is a horizontally split machine with many axial-flow stages. Steam turbine drivers offer speed match (direct drive, without gear unit) and variable-speed drive operation

forged, are generally specified for medium- or high-pressure CPI machines. For flammable or toxic process gases, a suitable steel grade is the minimum requirement for the compressor casings. Generally, casings should be heat treated regardless of thickness.

Many complex CPI applications cannot be accommodated by a single casing compressor. A good example is a high-pressure ratio service (say more than eight). Multiple compressor casings are commonly employed. A popular configuration is the tandem-driven series arrangement using a common driver. A gear unit may be included in the compressor train, either between casings or between the driver and the compressor casings.

Compressor component design

Shafts should be made of one piece, heat-treated forged low-alloy-steel, suitably ground. It should be forged as close as possible to the final dimensions. Forged, low-alloy shafts are standard shafts for process centrifugal compressors. Only machines handling highly aggressive gases may have corrosion resistance shafts. Shaft sleeves are frequently fitted so that sealing elements do not operate directly against the shaft.

Two types of impellers are commonly used: a closed impeller (consisting of a hub, blades and a cover) and a semi-open impeller (consisting of a hub and blades). The semi-open impeller is most often called an open impeller for simplicity.

Impellers are fabricated by weld, braze, mill, electro-eroded or cast (most often fabricated using forged components). Plating and other methods of metal buildup on an impeller are generally unacceptable. Impellers need heat treatment (stress relief). Semi-open impellers offer a high flow coefficient. They are usually used for gases with a molecular weight below 40. Semi-open impellers introduce more vibration and dynamic issues compared to the closed-type.

Closed impellers have a smaller axial length than the semi-open type, and are easier to fabricate. These impellers are more popular in modern centrifugal compressors (except integrally geared and overhung machines that use semi-open impellers). Impellers are shrunk onto the shaft, either hot or hydraulically. For shrinking on impellers, great care should be taken. When cooling down, the impellers should not pull a bend into a shaft. Some compressors use polygon-fitted impellers.

It is economically desirable to use the smallest possible compressor. The higher the flow coefficient, the larger the suction rate for a given impeller diameter. For a multi-stage compressor, the first stage impeller is chosen to have the maximum flow coefficient. Sometimes a semi-open impeller is used for the first stage; however this configuration is rarely specified today. The flow coefficient of the subsequent impellers decreases as inlet volume decreases, if the shaft speed is constant. In multi-casing trains, the first casing, because it has the highest suction volume, dictates the train speed. This could lead to increasingly sub-optimum designs as the suction volume

of the later stages decreases. The solution is to include a gear unit between casings since, for large pressure ratios (>8), it is advantageous to use a higher shaft speed at higher pressures (where the volumetric flow is smaller).

The head generated is fixed by the impeller dimensions; particularly by exit angle, the tangential tip speed and the slip. The head seen at the compressor delivery, because of internal losses, depends also on flowrate. However, the head required is mainly determined by the process conditions (downstream facilities). It is particularly important to identify all of the process duties to be met by a centrifugal compressor before ordering a machine (when compressor selection and design freeze). Once the centrifugal compressor design and dimensions are fixed, duties other than the specified range may not fall within the compressor operating envelope or can only be accommodated, if at all, by inefficient operation.

The maximum tip speed is governed by the following:

Strength limitation. The majority of process impellers are manufactured from low-alloy steels, and tip speeds for closed impellers will be limited to approximately 310 m/s. For semi-open impellers, particularly overhung ones, tip speeds up to 400 m/s are acceptable. Compressors handling corrosive gases, such as wet H_2S, require relatively low strength materials to satisfy NACE (National Assn. of Corrosion Engineers) guidelines. The limit is usually around 250 m/s.

Mach number. The maximum tip speed is also limited by sonic considerations; therefore the gas Mach number should be limited to avoid choking. The critical Mach number occurs at the eye of the impeller. As a rough indication, the Mach number should be kept below about 0.85–0.9 to avoid choking at the inlet. Higher values may be used in very special designs.

For the minimum capital cost, the maximum permissible tip speed is selected. However, this may lead to a narrow operation range. A wider range and a higher efficiency is obtained if the tip speed is slightly reduced (say 5–10%) by increasing the number of impellers needed to achieve a given head. The lower limit of flow coefficients is dictated by the width of the impeller passage. The upper limit is dictated by the impeller shape or its Mach number.

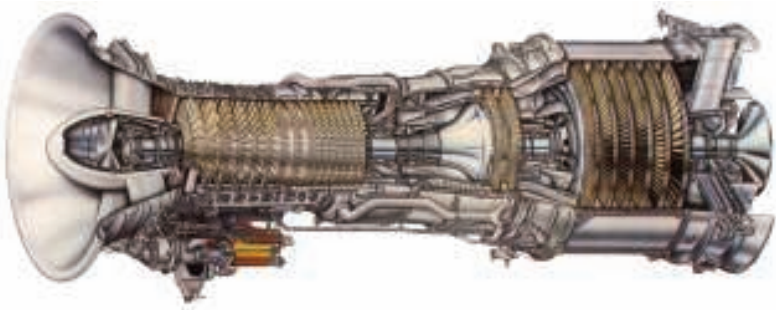

FIGURE 5. This gas turbine is a hot-end drive machine. A gas turbine is selected as a compressor driver based on available fuel and plant-specific requirements

Compressor manufacturers generally use standard impeller designs arranged in a series of shapes and sizes. Each family of impeller covers a range of flow coefficients. Impellers with a low flow coefficient are often one-dimensional or two-dimensional. Impellers with high flow coefficients, particularly semi-open impellers, are most often three-dimensional. Manufacturers of centrifugal compressors do not produce a continuous range of impeller diameters but rather have a series of sizes (usually in steps of 20–30%), covering impeller diameters from about 0.2 to 1.5 m.

An impeller's flow coefficient is a function of the impeller vane-tip angle, the outlet velocity and the stage efficiency. To avoid very narrow impeller passages, the tip angles for low flow impellers (impellers at the last stages) are usually made more acute, thereby reducing the impeller radial flow velocity (and allowing relatively wide impeller passage). However, this design reduces the pressure coefficient, which is further reduced by the low efficiencies of such impellers. In addition, the acute vane-tip angle results in the actual exit vector to be nearly tangential, which implies that operation is close to stalling and will rapidly lead to stalling if the flow is reduced. In a flow reduction scenario, the flow in the last impeller is proportionally reduced much more than in the first impeller. This is particularly critical for compressors operating with high pressure ratios. Impeller designs should be optimized with respect to all factors and considerations, such as efficiency, operation range, surge limit, choke flow and curve characteristics.

The permissible number of impellers per compressor casing is mainly a function of rotor-dynamic, Mach number, flow coefficients and impeller tip speed. The relationship between these parameters is complex, and the best advice is to check with the compressor manufacturer to determine the maximum number of impellers required for a given application. As an indication, four to nine impellers per compressor casing design are commonly used. As a rule of thumb, the maximum impeller number based on compressor arrangement, is as follows:

- In-line arrangement: nine
- Back-to-back configuration: eight
- Compressor with side stream(s): six

For low sonic velocity and a low flow coefficient (relatively thin, closed-type impellers), up to nine impellers per casing may be used. For high sonic velocity and high flow coefficient, the number of impellers per casing may be limited to four or five.

Process and performance

Temperature. The centrifugal compressor has been applied in an approximate capacity range of 2,500 to 420,000 m^3/h. Pressure ratio and pressure levels are difficult to describe in general terms because of the wide range of applications. As a rough indication, a pressure ratio of up to around four is available for semi-open impellers (mainly in single stage or integrally geared machines). Multi-stage machines (of process type) generally operate at a pressure ratio of less than or around two per closed-type impeller.

The higher the gas discharge temperature, the higher the compression

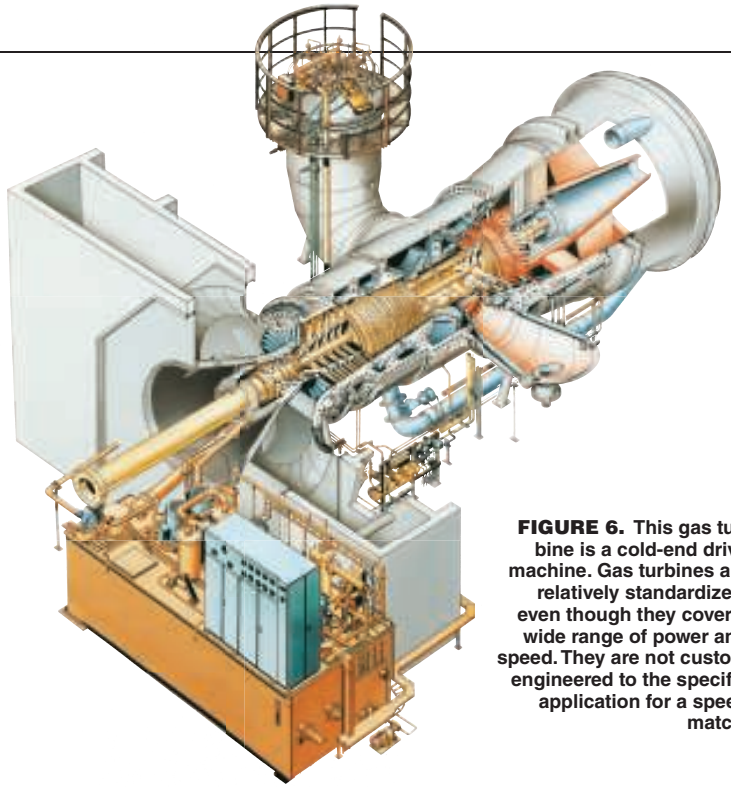

FIGURE 6. This gas turbine is a cold-end drive machine. Gas turbines are relatively standardized, even though they cover a wide range of power and speed. They are not custom engineered to the specific application for a speed match.

power. In the past, "isothermal compressors" with many cooling surfaces and intercoolers were popular. However, due to their high capital cost and excessive maintenance, they are not currently in production. By keeping the gas temperature low, significant amounts of power can be saved. Mechanical considerations usually limit the discharge temperature to about 250°C. But the commonly used sealing elements made from elastomers (O-rings for casing, or similar components) usually limit the top temperature to 170°C. Some gases must be kept at lower temperature based on process requirements (for instance, to avoid decomposition, reaction, polymerization or similar process reasons). Hydrocarbons are usually limited to around 120–130°C maximum temperature. Permissible gas temperatures for acetylene, chlorine, ammonia and carbon monoxide are around 60, 100, 160 and 175°C respectively. If the machine operates relatively close to the surge, a higher discharge temperature could occur. If the gas temperature is too high, inter-cooling must be provided.

Pressure margins. For applications where the pressure ratio can be defined fairly precisely, a 10% margin should be applied to capacity. For applications where the pressure ratio is heavily dependent on flow (for instance, with a recycle duty) a 5% margin should be applied to both capacity and head. Higher margins than these can only be justified if the operation and capital cost increase is acceptable. In some cases, extra margins are included in the anticipation of future debottlenecking. This may be economic where variable-speed drives are employed.

Performance. The characteristic (performance) curve of a centrifugal compressor is a plot of the head against the flow (capacity). For reliable operation, the head-capacity characteristic curve should rise continuously from the certified operating point to the actual surge point (usually 5–10% increase is specified). For compressors operating in parallel, the head is at the same specific flowrate needed within certain limits (most often 2%) at any flowrate on the compressor curve.

At flows greater than the design flow, the characteristic is limited by a rapid fall of head. This is due to the high losses, particularly in the frontal stages of the compressor, caused by the high gas velocities and incidence angles at the entry into the impellers.

Compressor drives

Historically, the most popular drive for the centrifugal compressor has been the steam turbine. A steam turbine can readily be speed matched to the compressor. Figure 4 shows an example of a steam turbine driver.

Electric motor drivers require, with some exceptions, that a step-up gear is used for speed match. Because fossil fuel can be more efficiently converted to electricity in large combined-cycle power plants (currently with efficiency more than 60%), the costs of electrical energy for electric motors become sufficiently low to displace the more convenient steam turbine drivers. Large electric motor drivers (currently up to 70 MW) using variable frequency conversion to provide for variable-speed, are very popular.

Gas-turbine drivers are common in some CPI applications, such as very large compressor units, remote areas, where cheap fuel is readily available or similar situations. The operating speed range of a gas turbine is standard for a given model. Sometimes the output speed of the gas turbine can be considered to design an efficient centrifugal compressor. Usually it is not possible, however, and so an intermediate gear unit is needed. As an indication, gas turbine drivers are employed in 5–140-MW drive power range for various CPI compressor applications. Figures 5 and 6 show examples of gas turbine drivers. ■

Edited by Gerald Ondrey

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A Method for Quantifying Pipe Vibrations

A technique to quantify vibration forces can help prevent pipe failures due to vibration-induced fatigue

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Reliance Refinery

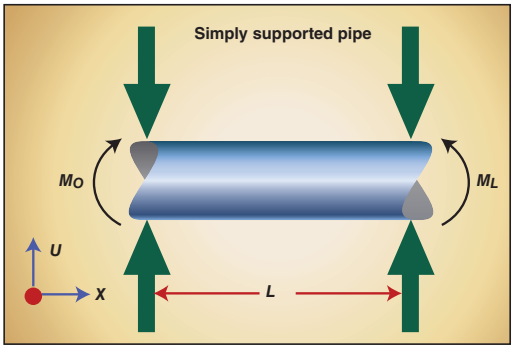

FIGURE 1. The span of pipe between two supported points can be measured for vibrations

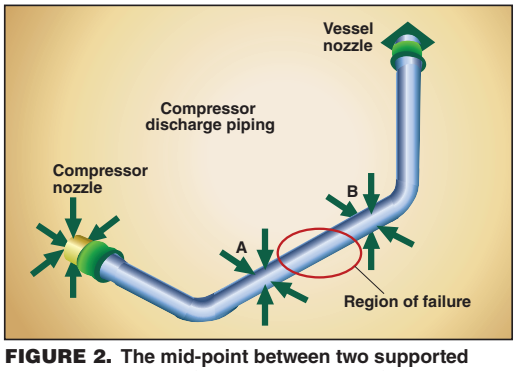

FIGURE 2. The mid-point between two supported points on a pipe is often where vibration failure occurs

Failures of piping due to vibration-induced fatigue are a serious problem in the chemical process industries (CPI) and a matter of concern for the safety and reliability of plant operations. Due to the complexity of flow-induced vibrations in pipes, no closed-form design solutions — those that can be expressed in terms of well-known functions — are available.

In this article, we present a method for quantifying vibration forcing functions for the optimal design of metal piping systems in the CPI, as well as an example of its use. The method is an analytical technique based on the theory of vibrations in the frequency domain (Inverse Theory of vibrations). The method can be easily adopted by practicing engineers.

VIBRATION MEASUREMENT

Piping systems experience various vibratory loads throughout their lifecycles. If not controlled, these pipe vibrations will lead to fatigue failures at points of high stress intensity and can even damage pipe supports. These failure scenarios could result in plant outages or in more severe consequences, such as fire or loss of human life. Thus, it is imperative that piping systems be safeguarded against such failures.

To avoid fatigue failures in piping systems, engineers carry out dynamic analyses of vibrations during a design adequacy check for a piping system. The major difficulty in dealing with the vibration problems lies in estimating the forcing function. If the exciting forces acting on the pipe can be quantified precisely, the system response can be determined with great accuracy by the existing analytical methods. But unfortunately, this is not readily possible in most cases, since the vibrations in an operating pipeline are flow-induced.

The complexity of flow patterns and the mechanism of force-coupling render the determination of the forcing function extremely difficult. In such a scenario, data — in the form of field vibration measurements in conjunction with analytical methods — can provide a basis for estimating the dynamic force and stress [*1–3*].

In our method, we analyze the problem in terms of the theory of vibrations in the frequency domain. We present a simple numerical technique that can be easily built into any of the common spreadsheet computer programs with the help of macros.

Current vibration approaches

The current practice for exploring pipe vibrations is the vibration screening criteria method. In this method, vibration response parameters, such as velocity or displacement, are measured in situ and compared against some established acceptance criteria, usually in the form of graphs known as vibration severity charts [*4*]. In the petroleum refining and petrochemical industries, these charts are used extensively. However, they are typically found to yield conservative estimates.

Another widely used tool is the ASME OM Code [*5*] — a standard followed for piping in the nuclear power industry. Here the vibration velocity for a piping span between two nodes is the criterion. The limiting value for pipe-vibration velocity is determined by an empirical relationship, which involves coefficients that depend on several parameters, such as weld arrangements, mass lumping, and others. When the peak value for the velocity is less that 12.7 mm/s, it may be assumed that the piping has sufficient dynamic capacity. If the vibration exceeds this level, however, the ASME guide recommends reviewing the vibrations with more information on the potential causes and taking steps to reduce vibration levels.

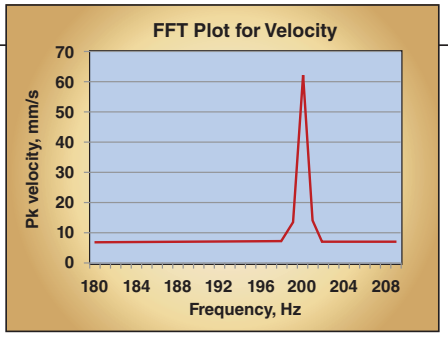

FIGURE 3. A fast Fourier tranform plot for a mid-span point shows high vibration speed

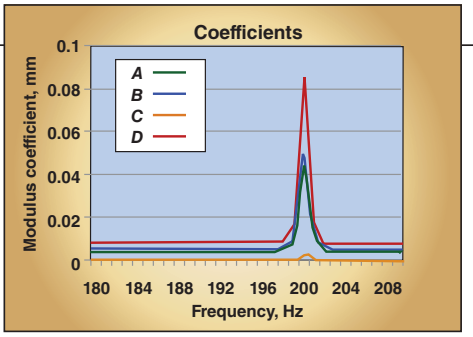

FIGURE 4. The peak at 200 Hz indicates the excitation frequency due to compressor pulsations

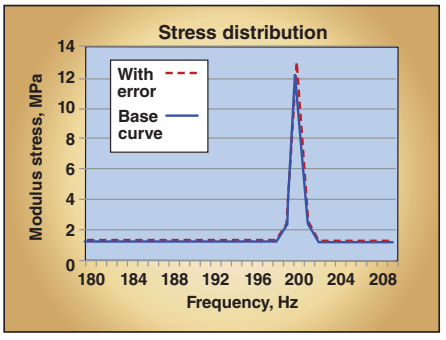

FIGURE 5. The vibration stresses exceed the endurance limit of the piping

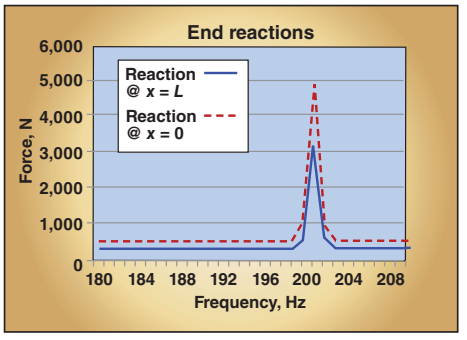

FIGURE 6. After error is introduced, the variation in the solution is similar to maximum error

NOMENCLATURE

L	Length of pipe span
x	Distance along the span
$\mathcal{D}$	Differential operator
ω	Circular frequency
σ	Stress
m	Mass per unit length
U	Displacement of pipe
$\hat{U}$	Fourier transform of U
k	Wave number
FFT	Fast Fourier transform
R	Reaction force
EI	Bending modulus
j	Square root of –1
$( )^T$	Vector norm
η	Loss factor
Z	Section modulus

We have observed the above methods to be conservative and to provide a "cookbook" or a "go/no-go" approach. They tell us only whether or not the vibrations are within acceptable levels. It is not possible to generate a quantitative estimate of the forcing function and of the actual stress levels on the pipes, both of which are essential for a design adequacy check. We studied the problem within the framework of Inverse Theory. We will focus on steady-state vibrations, because they have been found to cause maximum damage.

PROPOSED METHOD

Theoretically, for a simply supported pipe, the response at any location along the span may be determined by the vibration measurements at two distinct points in the span. The span is a straight portion between two fixed points or supports (Figure 1). A single point measurement near the mid-span is also sufficient. Further mathematical details are included in the second part of this article. The measurements could be realtime displacement, velocity or acceleration with the post-processed fast Fourier transform (FFT) plots. The calculations are straightforward and amenable to simple spreadsheet programming with macros.

Steps for implementation

The following are the steps needed to implement the method. The notations and equations mentioned in the steps are shown on p. 49.

1. Identify the pipe span in which the vibration is severe.
2. Take velocity readings at two points in the span. One of the points should preferably (but not necessarily) be the mid-span. The measurements can be made using any portable handheld accelerometers or realtime velocity-measuring devices. Finally, the time history readings are to be converted into FFT plots as output (a part of the post-processing features of the measurement devices).
3. As explained on p. 49, construct matrix G of size 4 × 4, as in Equation (10). The elements of the matrix are based on the material and the damping properties of the material.
4. Note that the matrix elements are complex quantities having real and imaginary parts.
5. Construct the vector V using Equation (12). The first two elements are 0; the remaining two are the measured FFT responses at the two points obtained from Step 2. The elements of V are also complex quantities.
6. The coefficients (A,B,C,D) are obtained as a solution vector X from Equation (13). As the quantities are complex, a suitable complex matrix solution routine is used.
7. The displacements at any location in the span can be calculated with the help of the coefficients using Equation (5).
8. The stresses and end reactions are calculated from Equations (14)–(16).
9. Repeat the procedure for a range of frequencies. The frequencies chosen should cover the peaks of maximum response.
10. From the above, the frequency variation of the output parameters, such as stress, and the reactions, are obtained. These responses are combined to obtain the results for stress and end reactions (for example, Equations (15)–(16)). Resultant values may be compared with those allowable, as an adequacy check. For example, the endurance limit may be considered as the allowable for the stresses for fatigue evaluations. The support member may be checked for the dynamic reactions.
11. If the response parameters are within allowable limits, terminate the procedure. Otherwise, make a modification based on engineering judgment, and repeat the procedure.

The numerical tool required is a simple matrix-solution routine for complex quantities. Such modules are readily available or may be easily

programmed using macros available in a standard spreadsheet.

Example problem

The method has been applied to vibrations in the discharge piping (8 in. nominal bore) leading from a refinery fuel gas (RFG) screw compressor up to the oil separator. Figure 2 shows the model for numerical simulation. The rotor frequency is around 3,000 rpm. Heavy vibrations, along with failures, in the small-bore connections have been reported. The goal was to study the problem and provide a solution for reducing vibration levels and preventing such failures in the future.

Vibration measurements were taken at the points of failure. An FFT displacement plot of a point in the mid-span is shown in Figure 3. There is a peak at 200 Hz (that is, four times the running speed), which is typical of screw compressor pulsations. The vibration velocity is around 62 mm/s, which is much higher than the ASME limit of 12.7 mm/s [5]. Hence for a comprehensive design check, the actual stresses and the support reactions are required. Also, there is no excitation source of forces in the span. The excitations are by the end moments.

Numerical simulation

FFT plots of displacements at points 0.25 and 0.5 of the pipe span have been considered as inputs. As the quantities are complex, both modulus and phase were required. From Equation (14), the coefficients are solved. The plots of coefficients A to D are shown in Figure 4. On their basis, the response (the stress and end reactions) were calculated (Figures 5 and 6). As a part of the error analysis, a random error with a peak magnitude of 1% was introduced into the measurements. The exercise was repeated and the resultant plots are also shown in Figures 5 and 6 for comparison.

Reduction of vibration stress

The plots (Figures 4–6) show peaks at 200 Hz, which is the excitation frequency due to pulsations generated by the compressor. The stresses are high and exceed the endurance limit.

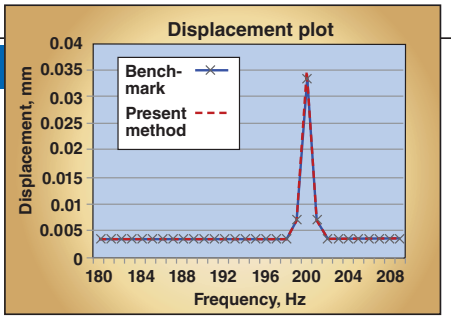

FIGURE 7. Results of the proposed method match those using finite element analysis

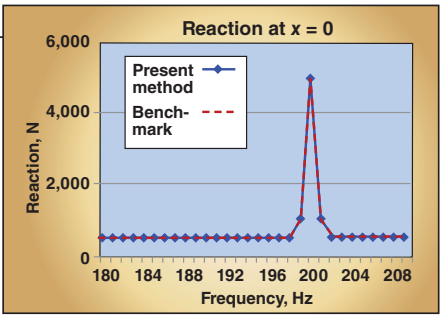

FIGURE 8. The proposed method requires no information on natural boundary conditions

As a check, a direct solution (benchmark) based on calculated end moments was obtained through finite element analysis (FEA) by standard commercial software. The results show a close match with those of the proposed method (Figures 7 and 8).

Figures 5 and 6 show the results after the introduction of the error. The variation in the solution is about the same order of magnitude of the maximum error, which is also in agreement with the theory.

A distinguishing feature of this method is that no information is required on the natural boundary conditions (BCs). This is remarkable since in the direct theory, the solution depends on the BCs, whereas in this inverse problem, the BCs do not play a role. This is also significant in the sense that practically, it is almost impossible to assess the true support conditions.

In order to reduce the stresses, the modes around the observed frequency of 200 Hz were identified. The modes were then iteratively shifted by means of additional restraints. The end moments were applied to determine the stresses and the reactions. The final configuration was achieved by further fine-tuning considering practical constraints. Figures 9 and 10 show the final configuration of the piping.

Vibration readings were again taken after the implementation of the recommendations (Figure 11). The maximum reported vibration velocity is around 5 mm/s. The results show a drastic reduction in the vibration levels, which proves the success of the resolution and vindicates the proposed method.

FIGURE 9. A view of the final configuration of the piping shows additional pipe supports

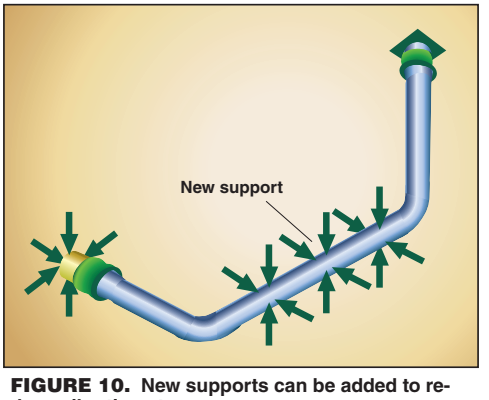

FIGURE 10. New supports can be added to reduce vibration stresses

Final assessment

Vibration failure in operational piping is a serious problem that requires comprehensive study and analysis to solve. In this sense, the proposed method has tremendous practical value. A quantitative method with proper mathematical basis has been provided as an alternative to the cookbook approach.

The method provides a basis for a proper engineering design, and can be easily adopted by engineers involved in troubleshooting. It should be acknowledged, however that troubleshooting vibrations in plant piping is the job of a specialist with experience in this field.

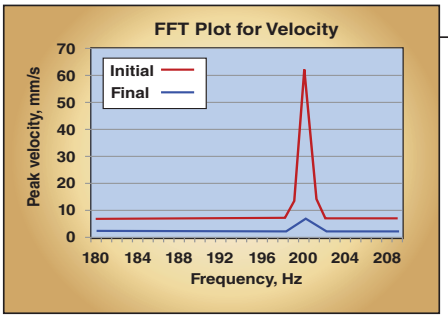

FIGURE 11. After modification, the maximum vibration velocity was reduced drastically

Mathematical background

The basic pipe configuration is shown in Figure 1. Considering the Bernoulli-Euler formulation and structural damping, the dynamic equation of motion in the frequency domain [*6*] is as follows:

$$\omega^2 \hat{U}(x,\omega) + [EI(1-j\eta)/m)D^4 \hat{U}(x,\omega)] = 0 \quad (1)$$

$$\hat{U}(x,\omega) = 0 \quad and \quad \hat{U}(L,\omega) = 0 \quad (2)$$

$$EID^2 \hat{U}(x,\omega) = M_0(\omega)$$

$$\text{and} \quad EID^2 \hat{U}(L,\omega) = M_L(\omega) \quad (3)$$

Equation (1) pertains to steady-state vibrations with the frequency dependence on ω. Here, the variables $\hat{U}$, M_0, M_L are complex, arising out of the Fourier Transform. BCs (Equation (3)) imply that the excitation at the ends is by moments, which is the source of vibration of the pipe in this span. The damping component has been expressed in terms of the loss factor η [*7*], which is a function of ω. The solution of Equation (1) (which is also termed a wave solution [*6,7*]) can be written as:

$$\hat{U}(x,\omega) = A(\omega)\exp(jkx) + B(\omega)\exp(-jkx) + C(\omega)\exp(kx) + D(\omega)\exp(-kx) \quad (5)$$

The complex coefficients *A*,*B*,*C* and *D* are independent of *x*, but dependent on ω. The first two terms of Equation (5) represent travelling waves from the left and right ends respectively. The last two terms represent evanescent waves that rapidly decay away from the boundaries. The complex wave number *k* may be expressed as follows [*7*]:

$$k = k_{re} + jk_{im} \quad (6)$$

$$\text{where} \quad k_{re} = \sqrt{\omega}\,(m/EI)^{0.25} \quad (7)$$

Here, k_{re} is the wave number for the undamped case and k_{im} may be expressed as:

$$k_{im} = -0.25 \times k_{re} \times \eta \quad (8)$$

The complex coefficients can be obtained by the following matrix system:

$$GX = V \quad (9)$$

where *G* is the matrix

$$G = \begin{pmatrix} 1 & 1 & 1 & 1 \\ \exp(jkL) & \exp(-jkL) & \exp(kL) & \exp(kL) \\ \exp(jkx1) & \exp(-jkx1) & \exp(kx1) & \exp(-kx1) \\ \exp(jkx2) & \exp(-jkx2) & \exp(kx2) & \exp(-kx2) \end{pmatrix} \quad (10)$$

$$X = (A\ B\ C\ D)^T \quad (11)$$

$$V = (0\ 0\ \hat{U}m(x_1,\omega)\quad \hat{U}m(x_2,\omega))^T \quad (12)$$

Here, *X* is the solution vector and *V* is the vector comprising the displacement measurements (from the FFT) at points x_1 and x_2 in the span. It can be observed that the determinant of *G* is nonzero. Hence, *G* is invertible and *X* can be solved uniquely as:

$$X = G^{-1}V \quad (13)$$

After the coefficients are obtained, other response quantities like velocity and stress can be computed. For stress, we have the expression as follows:

$$\sigma(x,\omega) = (EI/Z)D^2 \hat{U}(L,\omega) \quad (14)$$

The stress function is a complex quantity and has a continuous dependence on frequency, which varies theoretically from −∞ to ∞. However, for practical purposes, the response is dominated by some finite number *N* modes or frequencies. We can define the total stress as the square root sum of squares (SRSS) combination of the individual components.

$$\sigma_T(x) = \left(\sum_{i=1}^{N} |\sigma_i|^2\right)^{0.5} \quad (15)$$

Here, $\sigma_i = \sigma(x,\omega_i)$. Because the quantity is complex, the modulus has been used for the combination. In the same vein, the end reactions may be obtained as follows:

$$R_T(x) = \left(\sum_{i=1}^{N} |R_i|^2\right)^{0.5} \quad (16)$$

The SRSS method has been used for the computation of the resultants for stress and the reaction forces. This method is simple, reasonably accurate and also widely used. Alternatively, for a more rigorous analysis, other combinations for cumulative fatigue evaluation, such as the rain-flow counting method or the more recent Dirlik's method [*8*] may be used.

The number of measurement points may be reduced to one. This is because of the exponential terms in the matrix *G*. One of the coefficients, *C* or *D*, becomes negligible and we are left with three coefficients. ■

Edited by Scott Jenkins

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Magic trays, brown solvent

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

Every five years or so, a call would come in and once again I would be troubleshooting a certain extraction unit in Canada — usually in the dead of winter. This particular unit had a liquid-liquid extractor, a stripper, a vacuum regenerator and the usual complement of pumps, pipes, valves, vessels, heat exchangers, raccoons and crows. Some of you might remember the extractor from my Crow's Nest column (*CE*, February 2011, p. 21).

The natural state of the extraction solvent was clear and slightly yellow. With time, however, oxygen would creep into the unit, especially via the vacuum regenerator. Organic acids would form. The acids would eat any carbon steel that they encountered. Iron oxide and carbonaceous materials would accumulate in the solvent, which would turn from yellow to green to brown and then black. Eventually the solvent would look and feel like the three-year old engine oil in my 1974 Ford Falcon.

One troubleshooting visit was in response to a complaint about reduced recovery. The unit was shut down for the annual turnaround. My colleague, Reese, and I decided to enter and inspect the extractor at three manhole locations, starting with the top manhole. The top manhole was open. According to our drawings, the top tray was only about 3 ft below the top manhole. We inspected the top tray with our flashlights. It looked fine — no fouling. Then, Reese entered the column feet first, on his belly. He almost fell 20 ft.

Unfortunately, Reese and I failed to expect the unexpected. The top tray was there — but it wasn't. It was paper thin. It crumbled to dust instantly under his weight. Fortunately he was wearing a harness with a lanyard. It turned out that the top ten trays were similarly thin. Replacement trays were provided to the plant owner on an emergency basis.

Five years later, Reese and I were called to the plant again. The lean solvent was no longer lean. The focus was on the stripper. The pressure drop across the stripper was too low. We asked if we could enter the tower, for an inspection, at the next turnaround. A few months later, we heard that the column had been entered without our presence. Ten of the forty stripper trays were found to have been eaten away by acids. Without our input, all of the trays had been replaced with an unusual packing technology. We also heard that the packing technology was under-performing the acid-ravaged trays. Again, replacement trays were provided to the plant owner on an emergency basis.

In extraction units, solvent maintenance programs are of critical importance to the longevity of the units. Oxygen ingress needs to be minimized. To neutralize acids, bases can sometimes be added to the solvent. A black solvent will seem to work okay for short time periods, but eventually the trays, packings and packing distributors will plug up. Even worse, sometimes your column internals will disappear — presto! ■

Mike Resetarits
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Rules of Thumb For Pneumatic Conveying Pipelines

Proper design, configuration and layout of the conveying pipeline are critical for successful and troublefree operation

Amrit Agarwal
Pneumatic Conveying Consultants

Quite often, during the design of conveying systems, not enough attention is paid to the design of the conveying pipeline and its components. This disregard often leads to some major conveying system problems such as low conveying rates, conveying line plugging, excessive wear and tear in the conveying line, high conveying system pressure drop, product breakage, fines and streamer generation and product cross-contamination. Guidelines presented below help mitigate or avoid such problems.

General considerations

Materials of construction. For the pipe itself, use carbon steel if contamination is not an issue. Otherwise, use aluminum or stainless steel. Use stainless steel for food and pharmaceutical applications. For special applications such as abrasive solids, high temperatures, and so on, it is necessary to find a suitable material for the conveying line and its components.

Pressure rating. Pressure rating of the conveying pipeline should be suitable for the maximum conveying pressure of the conveying system. For most applications with a Roots type blower, a pressure rating of 30 psig is satisfactory. This rating corresponds to the rating of a Schedule 10 pipe. Use thicker pipes, such as Schedule 20, 30 or 40 for higher pressure applications.

Temperature rating. The temperature rating of the conveying pipeline should be suitable for the minimum and maximum temperatures experienced by the conveying line. These temperatures depend upon the ambient temperature, conveying air temperature and solids temperature.

Pipeline joints. Pipeline segments must not be welded to each other because of the need for dismantling of the pipeline. These segments should instead be joined to allow easy dismantling of the pipeline. Flanges can be used, but they are expensive and not easy to unbolt. They should be used where the joint must be 100% leak proof. Use of easy-to-open pipeline couplings is common. Locate the joints for easy access to allow dismantling of the pipeline when necessary.

The inside diameter of the couplings or the flanges must be equal to the inside diameter of the pipe. Both ends of the adjacent pipe segments must be truly aligned with each other so that there is no internal protrusion and there is no gap between the two ends.

Pipeline internal surface. The inside surface should be clean and free of oil and rust. A smooth interior can be used, except when handling plastics that can generate so-called streamers (a product of plastic degradation). In that case, inside surface is roughened by special tools.

For instance, dilute-phase conveying lines in pelleted plastics service are generally roughened on the inside surface to prevent streamer formation. (Other common names for streamers are angel hair or snake skins). Streamers are formed when a plastic particle at a high conveying velocity strikes the smooth pipe wall at a low angle of incidence. The energy of impact is enough to melt the particle surface at the point of contact and leave a thin crayon-like film mark on the pipe wall. This thin film continues to grow in length due to subsequent impacts, cools quickly, and peels off from the pipe wall in the shape of a streamer. The length of this streamer may be a fraction of an inch or two to three feet in length, or even longer. Long thin streamers tend to float and swirl on the air current in storage vessels until they ball up to form something that resembles a bird-nest.

In any case, the net result of streamers is plugged slide gates, feeders, screeners, mechanical conveyers, and hoppers. The best solution to solve this problem is to avoid making streamers, which is done by roughening the inside of the pipeline. Roughening (or scoring) is done by a special shot-peening method, either using inhouse specifications or vendors who have this expertise. Vendors have their own proprietary techniques for applying the scoring. A well scored pipe should last at least one year before it needs to be re-scored.

Aluminum elbows should be an-

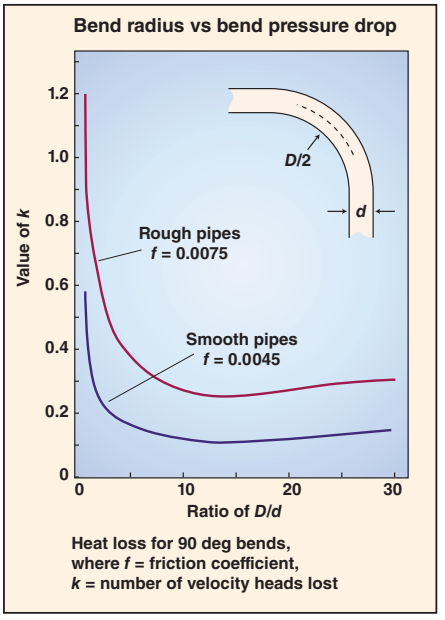

FIGURE 1. Studies show that long radius bends (larger *D*/*d*) have a lower pressure drop (lower *k*)

odized to increase the life of scoring particularly when conveying hard or abrasive materials. As an option, stainless steel elbows can also be used depending upon their relative cost.

Although scoring is recommended for conveying systems that handle soft plastics, it has two distinct disadvantages. Pressure drop through the conveying system is higher than that in smooth pipes, and some particle attrition results because of the roughened surface. In pelleted plastics systems, the amount of fines generated is significant. It will then be necessary to elutriate or air wash the pellets at the end of the conveying system.

Static charges. When handling solids that generate a static charge, pipelines must be built to conduct this charge to the ground. Pipeline joints must allow this charge to flow to the ground by using static conducting jumpers across each joint. After assembly of the pipeline, check its resistance to ground, from the beginning to the end. It should not exceed 1 Ohm.

Pipeline supports. Pipes come in standard 20-ft lengths. Therefore, provide supports for the pipeline every 20 ft or less. Locate these supports to prevent any sags in the pipeline due to its weight. After installation, make sure that the pipeline is straight and not sagged. If the pipeline can expand due to high temperatures, design the supports to allow for this expansion. Locate the pipeline so that it has easy access for dismantling.

Bends. Material of construction, pressure rating, and temperature rating of the bends should be the same as that of the pipe. Standard short-radius bends are not used in conveying lines because of pressure drop considerations. Studies show that long radius bends have a lower pressure drop. Results from these studies are shown on Figure 1. Long radius bends with a bend-radius to pipe-diameter ratio of 8–10 have a lower pressure drop.

Some vendors have developed special bends such as Hammertek, Vortice Ell, Gamma bend, or blind tees and so on, to reduce product degradation and bend erosion.

Air or gas supply line. Keep the length of this line as short as possible by locating the blower close to the solids inlet or outlet point. Minimize the pressure drop in this line by using a large diameter line if needed. Carbon steel construction can be used, except for in food and pharmaceutical applications. Pressure and temperature rating can be the same as that of the conveying pipe. Provide a check valve in this line upstream of the solids inlet (for pressure type systems), or downstream of the outlet point (for vacuum type systems) to prevent solids from backing-up into the conveying blower.

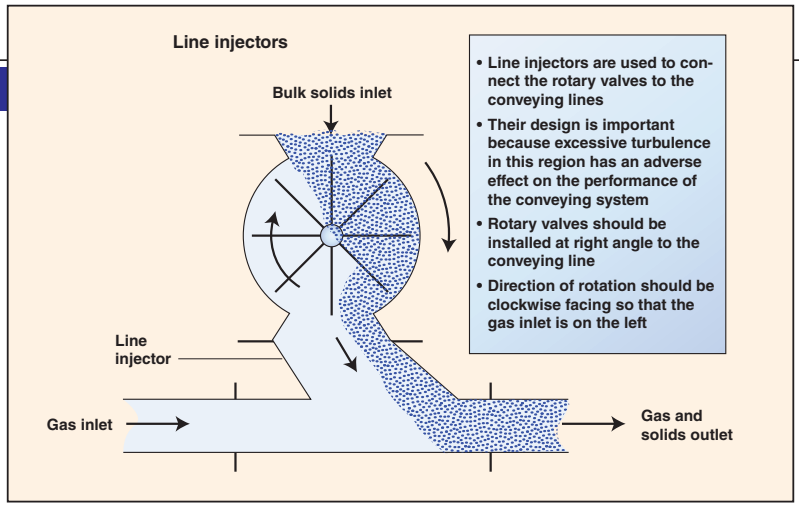

FIGURE 2. A good line injector design allows the material's downward flow and the leakage air's upward flow without interfering with each other, thereby minimizing turbulence in the feed zone

Diverter valves

Diverter valves are used to divert the flow of solids and air from one conveying line to either of two destinations or from either of two conveying lines into one conveying line. The most critical features of diverter valves are as follows:

- Positive shutoff so that there is no air or solids leakage from the used port to the unused port. This is done by using gas tight seals
- Full port design so that the internal cross-sectional area of the valve is essentially the same as that of the conveying line

These valves are made in various designs but so-called tunnel, channel or plug types are more common. The divert position is at either 30 or 45 deg to the through position. Prefer to use tunnel- or channel-type diverter valves as they will have lower pressure drops.

Keep the pressure rating of the valve the same as that of the conveying pipeline. The pressure rating of the valve housing is generally 150 psig, and the pressure rating of the channel or plug should be the same as that of the conveying line.

To prevent valve seizing, make sure that the valves are designed to operate at the lowest ambient temperature along with the highest internal temperature.

Diverter valves can be operated by hand wheels, T handles, air pistons, hydraulic cylinders or electric motors. Limit switches for the divert or through indicators are installed in many cases to sense the valve position, depending on the degree of instrumentation required for the process. During the time the position of the valve is being changed, it is necessary to shut down the conveying system and clear the conveying line of solids. This time is typically about 15 s.

Material of construction of the valves depends upon the application and solids being conveyed. The most common materials of construction are a cast aluminum body and end plates with a stainless steel plug and stainless steel shafts. Aluminum may be anodized for better wear. Provide seals and packing to prevent leakage through or to the outside of the valve. To prolong life, use stainless steel plugs even if using aluminum conveying lines. This is to minimize abrasive wear of the surface due to high-velocity solids impact. The body can be aluminum or stainless steel.

Valves must be able to divert very fast. A divert time of less than five seconds is desirable.

Diverter valves, flapper type

Flapper type diverters are not suitable for use in pneumatic conveying lines. They are mostly used to control solids

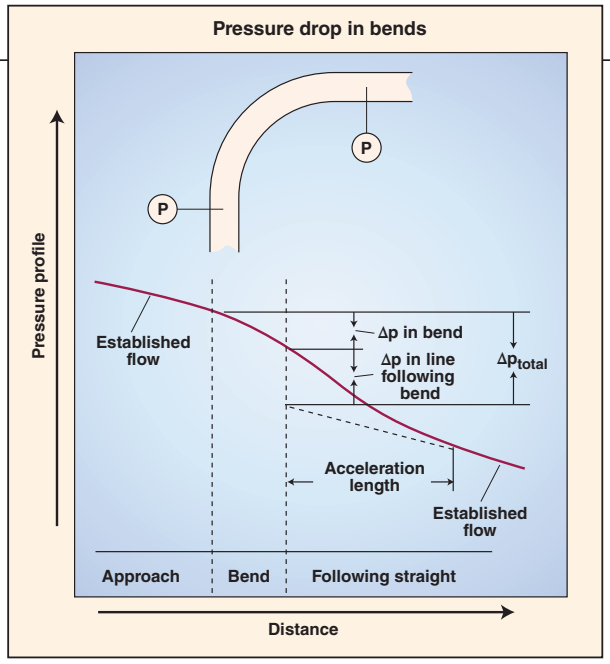

FIGURE 3. The total pressure drop in the bends is the sum of pressure drop in the bend, and pressure drop in the pipeline after the bend for recovery of solids conveying velocity

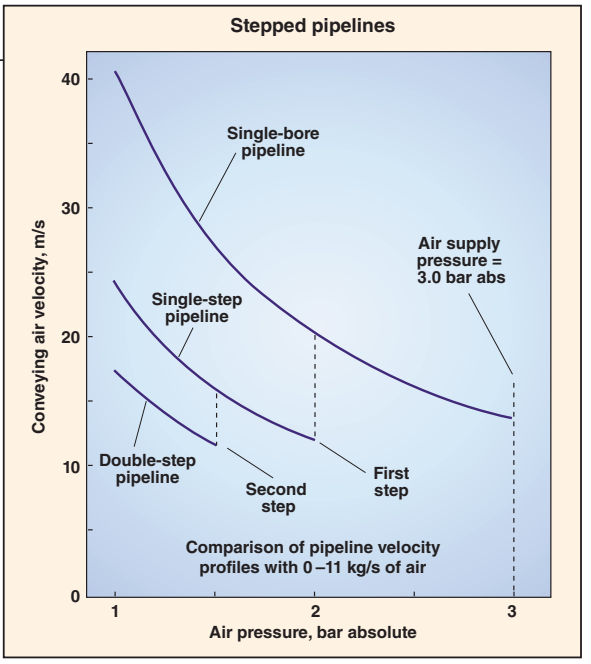

FIGURE 4. Stepped pipelines are used to reduce the conveying velocity in long conveying lines by increasing the pipe diameter (by stepping-up the diameter) partway along the line. This figure shows two steps in the conveying line

flow from low-pressure bins (less than 2 psig). In most cases, solids flow must be stopped by a shut-off valve located above the diverter before changing the flapper position because its position cannot be changed easily if the line is full of solids.

- The valve diameter should match that of the connecting feed chutes
- Use a stainless steel flapper to minimize wear. Housing can be aluminum or stainless steel. The flapper should close fully in either position
- The pressure rating of the valve should match that of the connecting feed chutes

Flexible hoses

Flexible hoses are not used in conveying lines except for short distances, such as in unloading bulk containers like rail cars and trucks. There are several reasons for this. It is difficult to keep flexible hoses in straight horizontal or vertical configuration and they have a tendency to sag and form bends. Their pressure drop is higher than that of pipelines. They also wear out both internally and externally.

Flexible hoses can be metallic or synthetic. Synthetic hoses come with internal spiral-wound metallic liners to improve strength and durability. When conveying static-generating solids, conductive hoses are used. Metal hoses are generally braided stainless steel with a stainless-steel internal liner to prevent air leakage.

Disadvantages of flexible hoses include the following:

- Higher pressure drops than metal pipe due to a higher loss of the solid's kinetic energy
- Frequent hose failures caused by bending and handling
- Difficulty in manual handling of large diameter hoses (6-in. and above)
- Manual hose connections that are not easily included in process system control logic

Considerations to be considered in hose selection include the pressure rating of the hose, connection methods of flanges and nipples to the hose, considerations of failure consequences, proper static grounding, and minimum bend radius of the selected hose.

Slide gate valves

Guidelines for slide gate valves include the following:

- Use bi-directional, resilient seated valves so that they may close fully even with a head of solids
- Do not use valves with metal seats or internal ledges because solids may accumulate on these ledges, cause difficulty in fully closing the valve and may result in product cross contamination
- For applications that need corrosion protection, use cast, 316 stainless-steel construction for the body and gate
- Body style should be wafer type
- Valve packing should be white square-braid acrylic filament with polytetrafluoroethylene (PTFE)
- Seat material should be white Viton
- The yoke should be stainless steel
- Provide purge gas in the bonnet section to prevent dust buildup inside the bonnet

Design and installation of the slide gate valves should maintain the flow pattern from the bin above. If it is a mass flow bin, the slide valve must maintain mass flow. This requires that the valve's inside diameter is the same as that of the bin outlet and that the valve is used only in a fully open or fully closed position.

Gas tight designs may be required if the bin above contains gases such as hydrocarbons or nitrogen.

Shut-off and control valves

Shut-off valves, check valves, or control valves are not used in conveying lines to stop or regulate the flow of the solids and air mixture because they interfere with operation of the conveying system.

Line injectors. Line injectors are used to inject solids into the conveying line. Figure 2 shows a line injector to feed solids from a rotary valve into a conveying line. This design allows the

solids to trickle down into the conveying line instead of falling vertically down and forming a heap.

Route and layout

Minimize pressure drop. Guidelines for minimizing pressure drop include the following:

- Select a pipeline route that is the shortest distance to the destination including both horizontal and vertical lines
- Minimize the number of bends in the pipeline because bends are a major source of pressure drop. Solids velocity reduces in the bend due to wall friction and impact and then increases in the subsequent straight section of the pipeline, resulting in additional pressure drop (Figure 3 shows the affect of a bend on pressure drop)
- Do not use standard bends because they have the highest pressure drop. Use bends with a bend inside-diameter to bend-radius ratio of about ten. Tests show that pressure drop in such long-radius bends is less than that in smaller radius bends
- Try using diverter valves with a 30-deg. divert angle instead of 45 deg. A 45-deg. divert angle has twice the pressure drop

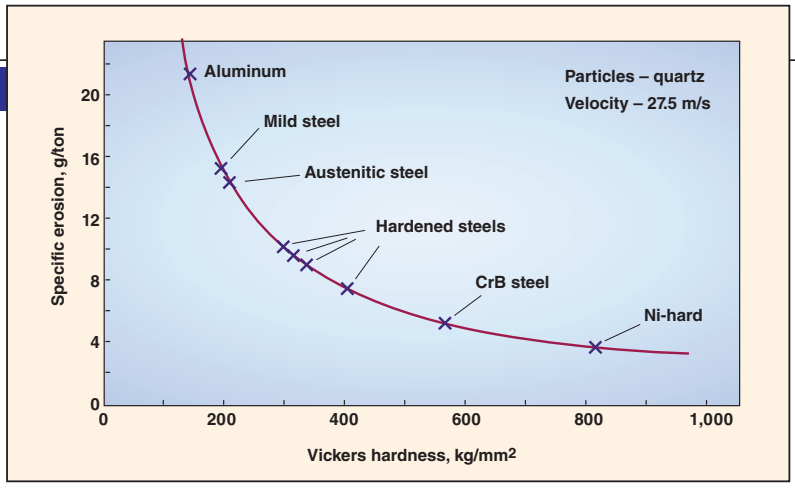

FIGURE 5. Harder materials of construction for the pipeline reduce pipeline wear significantly

Maintain conveying velocity. Select a design that maintains the required solids velocity throughout the conveying line to prevent saltation and line plugging. Solids velocity in the pipeline must not fall below saltation velocity to prevent line plugging. This is done by using the following criteria:

- From the pick up point to the first bend, make sure that the conveying line is horizontal and long enough to accelerate the solids to a velocity that is high enough to prevent saltation in the bend. Solids velocity reduces in the

bend due to impact and wall friction. This reduction can be 5–50% depending upon the solid. For a 50% reduction, solids velocity entering the bend must be at least 50% higher than the saltation velocity. In general, length of this horizontal line is at least 20 ft, but use a longer line where possible.

- After the first bend, locate the second bend to provide a sufficiently long horizontal line that will allow the solids to reaccelerate to the same velocity as was at the inlet of the first bend
- Do not install bends back to back but at a sufficient distance from each other to allow the solids to re-accelerate
- For long conveying lines, increase the pipe diameter at a suitable point in the pipeline route to prevent very high velocities. Select this point at which the solids velocity does not fall below the minimum conveying velocity. Figure 4 shows a pipeline with two increases in pipe diameter
- Conveying gas can leak from pipe couplings, diverter valves, rotary valves, and other fittings. Use gas tight equipment or increase the supply air flow for these losses
- Avoid using upward sloping pipelines because of loss of solids velocity due to wall friction.

Minimize solids breakage. High conveying velocity results in breakage of fragile solids particles. For fragile solids, this breakage can be proportional to the velocity to the third or fourth power. If this breakage is unacceptable, use a low velocity, dense-phase system or keep the velocity as low as possible.

Minimize pipeline erosion. When handling abrasive solids, it is important to use special material of construction for the pipeline to prevent pipeline erosion. Bends in the pipeline are eroded faster than straight pipe. To minimize this problem, use special bends with wear-resistant surfaces, or bends that have replaceable outer backs. Do not use soft materials such as aluminum. Determine the abrasiveness of the solids before selecting a suitable material for the pipeline. Reduce conveying velocity as much as possible, because wear increases to velocity to the 2.5 power or more. If the velocity is doubled, wear increases six times. See Figure 5 for a relationship of this wear between different materials. ■

Edited by Rebekkah Marshall

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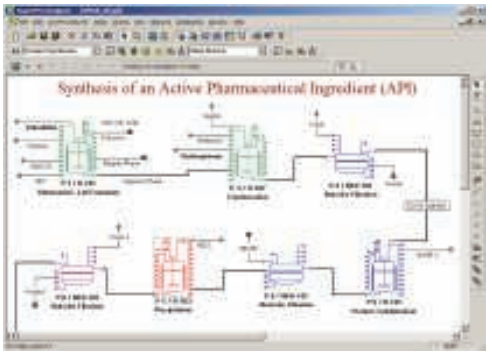

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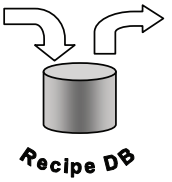

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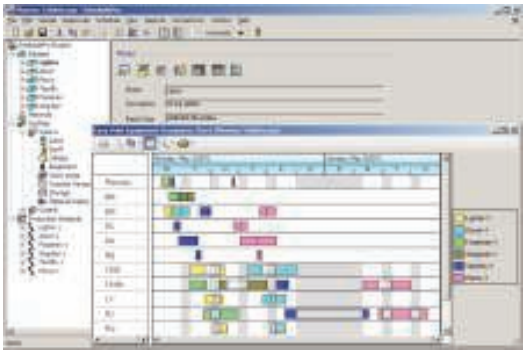

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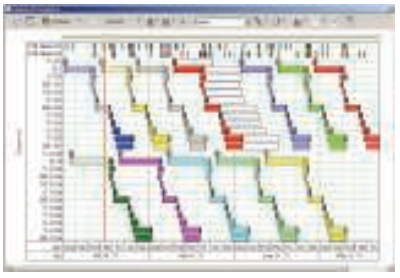

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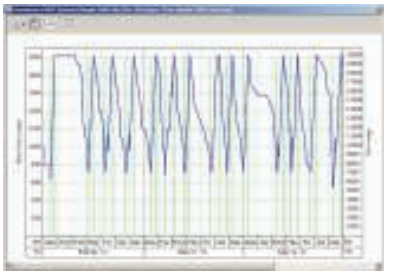

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13 Metallurgical & Metal Products
14 Engineering, Design & Construction Firms
15 Engineering/Environmental Services
16 Equipment Manufacturer
17 Energy incl. Co-generation
18 Other_____

JOB FUNCTION

20 Corporate Management
21 Plant Operations incl. Maintenance
22 Engineering
23 Research & Development
24 Safety & Environmental
26 Other_____

EMPLOYEE SIZE

28 Less than 10 Employees
29 10 to 49 Employees
30 50 to 99 Employees
31 100 to 249 Employees
32 250 to 499 Employees
33 500 to 999 Employees
34 1,000 or more Employees

YOU RECOMMEND, SPECIFY, PURCHASE

(please circle all that apply)

40 Drying Equipment
41 Filtration/Separation Equipment
42 Heat Transfer/Energy Conservation Equipment
43 Instrumentation & Control Systems
44 Mixing, Blending Equipment
45 Motors, Motor Controls
46 Piping, Tubing, Fittings
47 Pollution Control Equipment & Systems
48 Pumps
49 Safety Equipment & Services
50 Size Reduction & Agglomeration Equipment
51 Solids Handling Equipment
52 Tanks, Vessels, Reactors
53 Valves
54 Engineering Computers/Software/Peripherals
55 Water Treatment Chemicals & Equipment
56 Hazardous Waste Management Systems
57 Chemicals & Raw Materials
58 Materials of Construction
59 Compressors

1	16	31	46	61	76	91	106	121	136	151	166	181	196	211	226	241	256	271	286	301	316	331	346	361	376	391	406	421	436	451	466	481	496	511	526	541	556	571	586
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15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360	375	390	405	420	435	450	465	480	495	510	525	540	555	570	585	600

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People

WHO'S WHO


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Tim Spehar becomes manager of contract services for **Haviland Products Co.** (Grand Rapids, Mich.), a provider of chemical formulation, blending and packaging services.

Trostel Ltd. (Lake Geneva, Wisc.), a manufacturer of custom seals, precision-molded rubber products and custom rubber compounds, appoints *Jay Longbottom* CEO.

Suellen Torregrosa is named president of **Milton Roy Europe** (Pont-SaintPierre, France), a manufacturer of dosing, mixing and fluid-control technologies.

Hendrik Meerman joins **OPX Biotechnologies** (Boulder, Colo.), a developer of bio-based chemicals and fuels, as director of fermentation.

Synagro Technologies (Houston, Tex.), a biosolids-management company, names *Eric Zimmer* president and CEO.

Netzsch Pumps North America, LLC (Exton, Pa.) appoints *Julio Ferreira* vice president of sales, and *John Maguire* vice president of operations and product management.

Toray Plastics (America) Inc. (North Kingstown, Rhode Island), names *Chad Hedden* director of sales for the Lumirror Polyester Film Div.

Colin Minchom is promoted to vice president of the Particle Design Business unit of **Hovione** (Loures, Portugal), a maker of active pharmaceutical ingredients and intermediates. ■

Suzanne Shelley

BUSINESS NEWS

PLANT WATCH

Petrochemicals expansion project in the U.S. awarded to CB&I

April 9, 2012 — CB&I (The Woodlands, Tex.; www.cbi.com) has been awarded a contract by Williams Olefins, LLC for a petrochemicals expansion project in Geismar, La. Plant capacity is expected to be increased from 1.35 to 1.95 billion lb/yr. The scope of the award includes the license and basic engineering for the ethylene technology, the supply of the cracking furnaces, and the detailed engineering, procurement, and construction of the expansion project.

Ube to add production facilities for Li-ion battery separators to Sakai Factory

April 7, 2012 — Ube Industries, Ltd. (Tokyo, Japan; www.ube-ind.co.jp) is adding a production facility for battery separators to the Sakai Factory located in Sakai City, Osaka Prefecture. Startup is planned in early 2013, and by the end of 2014, the total production capacity is expected to be some 200-million m^2 from the two plants.

Russian Rosneft selects Topsøe technology for two hydrogen units

April 5, 2012 — The Russian oil company, Rosneft, has selected Haldor Topsøe A/S's (Lyngby, Denmark; www.topsoe.com) technology for two hydrogen units at the Kuibyshev and Syzran Refineries. Both units will supply hydrogen for the production of ultra-low-sulfur diesel fuel. The diesel fuel will meet the Euro 4 specifications, which come into effect in Russia in 2015. Each unit will have a capacity of 50,000 Nm^3/h, and will be based on Topsøe's radiant-wall SMR technology.

UOP to expand adsorbents and catalysts production at its Alabama facility

April 3, 2012 — UOP LLC (Des Plaines, Ill.; www.uop.com), a Honeywell company, says it will invest $20 million to expand its production facility in Mobile, Ala., to produce adsorbents and catalysts. The expansion is expected to be completed in the 4th Q of this year. The investment will expand production of UOP's Ionsiv ion-exchange adsorbents, which remove radioactive material from liquid, and are currently being used in Japan in response to last year's nuclear disaster.

Linde to construct onsite plants for Sadara's complex in Saudi Arabia

April 2, 2012 — The Linde Group (Munich, Germany; www.linde.com) and Sadara Chemical Co. (Sadara) have signed a longterm contract for Linde to supply Sadara with CO, H_2 and NH_3 at a chemical complex being built by Sadara in Jubail, Saudi Arabia. Linde will be investing $380 million in the project.

Toyo and ENPPI awarded ethylene plant contract for Ethydco

March 28, 2012 — Toyo Engineering Corp. (Toyo; Chiba, Japan; www.toyo-eng.co.jp) has been jointly awarded, with ENPPI — an engineering company under the Egyptian Ministry of Petroleum — a contract to build a 460,000-ton/yr ethylene plant and a 20,000-ton/yr butadiene extraction plant as part of Ethydco's petrochemical complex to be established in Alexandria, Egypt, and owned by Ethydco, the Egyptian Ethylene and Derivatives Co. The plant is scheduled for startup in early 2015.

Lucite International boosts MMA and MAA production in the U.S.

March 23, 2012 — Lucite International, Inc. (Memphis, Tenn.; www.luciteinternational.com) is progressing with its investment to establish 150,000-ton/yr production of methyl methacrylate (MMA) in 2012 at its Beaumont, Tex. facility. The company will continue to produce MMA at its Memphis, Tenn. facility. In addition, Lucite is progressing to commence production of methacrylic acid (MAA) at Beaumont, with an expected capacity of approximately 23,000 ton/yr.

GEA builds milk-powder plant in New Zealand

March 26, 2012 — GEA Group AG (Düsseldorf, Germany; www.geagroup.com) has received an order worth more than €70 million from Fonterra in New Zealand for a new whole-milk-powder plant that utilizes GEA process technology. The spray dryer in the new plant will be the largest dairy spray dryer ever built with a capacity of 30 ton/h of whole-milk powder, equivalent to more than 4.4-million L/d of milk.

MERGERS AND ACQUISITIONS

Verenium sells oilseed processing business and licensed enzymes to DSM

March 27, 2012 — Industrial biotechnology company, Verenium Corp. (San Diego, Calif.; www.verenium.com), has closed a transaction with DSM Food Specialties B.V., a business group of Royal DSM (Heerlen, The Netherlands; www.dsm.com), in which Verenium has sold its oilseed processing business to DSM, licensed certain enzymes for use in the food and beverage markets, and will provide access to new gene libraries to be developed by Verenium. Verenium will receive $37 million in total consideration, including transaction and related expenses.

Air Products acquires Xebec's adsorption technology

March 23, 2012 — Air Products (Lehigh Valley, Pa.; www.airproducts.com) has acquired advanced adsorption technology assets for its Generated Gases product lines from Xebec Adsorption, Inc. (Blainville, Quebec, Canada). In this acquisition, Air Products purchased the technology, intellectual property and know-how related to structured adsorbents, beaded adsorbents, and rotary valves from Xebec. Terms of the acquisition were not disclosed.

Avantium and Danone sign development partnership for bio-based plastic

March 22, 2012 — Avantium (Amsterdam, The Netherlands; www.avantium.com) and Danone Research have entered into a joint development agreement for the development of PEF (polyethylene-furanoate) bottles for Danone. The agreement forms another cornerstone of Avantium's commercialization strategy to further co-develop the YXY technology (For more on this tehnology, see The Bio-Based Economy, *Chem. Eng.*, August 2011, pp. 14–16). Avantium has recently opened its pilot plant in Geleen, The Netherlands, with the capacity of producing 40 tons of PEF for application development.

ABB helps turn electronic scrap into high-grade products for Boliden

March 20, 2012 — ABB's (Zurich, Switzerland; www.abb.com) automation and power technologies are helping metals company Boliden AB (Stockholm, Sweden; www.boliden.com) expand its recycling facility — recovering copper and precious metals from electronic scrap. The new plant is adjacent to an existing electronic-scrap recycling facility at the Rönnskär copper smelter in northern Sweden. This expansion will almost triple recycling capacity from 45,000 to 120,000 metric tons a year, making it the largest e-scrap recycling facility in the world. For the new plant, ABB has supplied a comprehensive range of process-critical automation and power technologies, including the process control system. ■

Dorothy Lozowski

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May 2012; VOL. 119; NO. 5
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FOR MORE ECONOMIC INDICATORS, SEE NEXT PAGE

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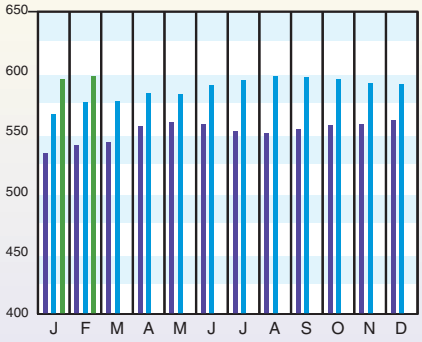
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Feb.'12 Prelim.	Jan.'12 Final	Feb.'11 Final
***CE* Index**	596.2	593.6	574.6
Equipment	730.6	726.8	696.6
Heat exchangers & tanks	689.9	686.7	654.4
Process machinery	677.8	676.1	653.5
Pipe, valves & fittings	933.5	924.9	868.3
Process instruments	433.8	427.8	440.8
Pumps & compressors	919.6	911.6	892.6
Electrical equipment	514.2	511.6	498.0
Structural supports & misc	772.9	776.1	732.1
Construction labor	321.5	321.1	326.2
Buildings	524.2	520.4	509.9
Engineering & supervision	328.4	329.9	334.9

Annual Index:

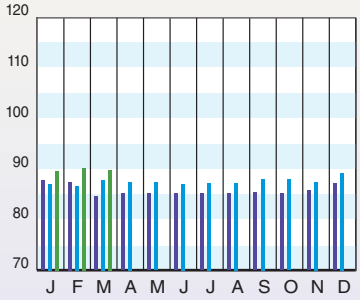
2004 = 444.2
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7



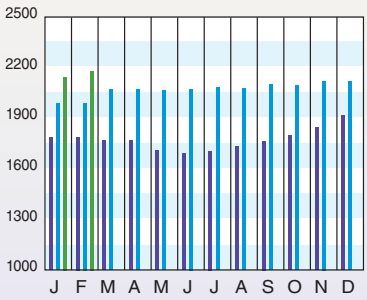
CURRENT BUSINESS INDICATORS

	LATEST		PREVIOUS			YEAR AGO		
CPI output index (2007 = 100)	Mar.'12 =	89.8	Feb.'12 =	90.2	Jan.'12 =	89.6	Mar.'11 =	87.8
CPI value of output, $ billions	Feb.'12 =	2,180.7	Jan.'12 =	2,144.8	Dec.'11 =	2,119.8	Feb.'11 =	1,990.4
CPI operating rate, %	Mar.'12 =	77.5	Feb.'12 =	77.9	Jan.'12 =	77.4	Mar.'11 =	75.7
Producer prices, industrial chemicals (1982 = 100)	Mar.'12 =	329.5	Feb.'12 =	318.1	Jan.'12 =	303.9	Mar.'11 =	317.5
Industrial Production in Manufacturing (2007=100)	Mar.'12 =	94.4	Feb.'12 =	94.6	Jan.'12 =	93.8	Mar.'11 =	90.0
Hourly earnings index, chemical & allied products (1992 = 100)	Mar.'12 =	156.8	Feb.'12 =	156.5	Jan.'12 =	158.7	Mar.'11 =	155.7
Productivity index, chemicals & allied products (1992 = 100)	Mar.'12 =	106.6	Feb.'12 =	107.1	Jan.'12 =	107.4	Mar.'11 =	110.8

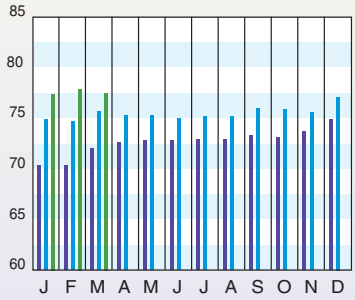
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

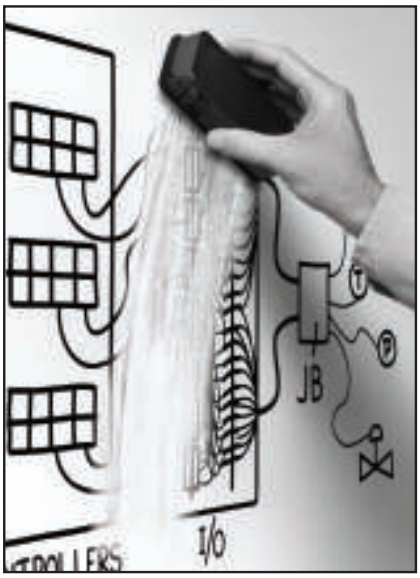
CURRENT TRENDS

Capital equipment prices, as reflected in the *CE* Plant Cost Index (CEPCI), increased 0.4% from January to February. The April 2011 issue of *CE* released the annual 2011 CEPCI, 585.7, which is an 6.3% increase from 2010 and an 11.4% increase from 2009. It also is the first annual number to surpass the previous peak of 2008.

Sales of chemicals at the wholesale level rose in February by 1.6%, to $9.8 billion, according to data from the American Chemistry Council (ACC; Washington, D.C.; www.americanchemistry.com). Chemical inventories also rose in February by 1.2%, to $11.5 billion. The inventories-to-sales ratio is higher now than compared to a year ago, suggesting that there may be "some imbalances building at this stage of the supply chain," an ACC report says.

Globally, China's economic growth slowed for the fourth quarter in a row, and is at its lowest pace in three years, the ACC report says, adding that a severe slowdown in China "is one risk to the global economy". Citing industrial production data from Europe, ACC says that the downturn there "may be easing."

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



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