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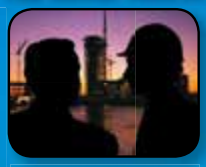

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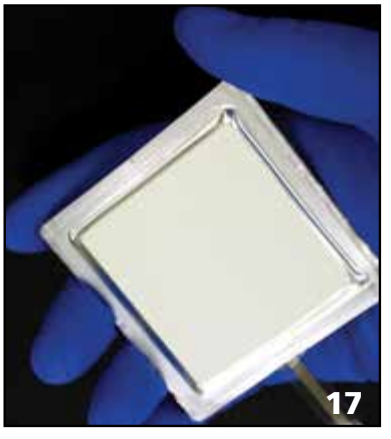

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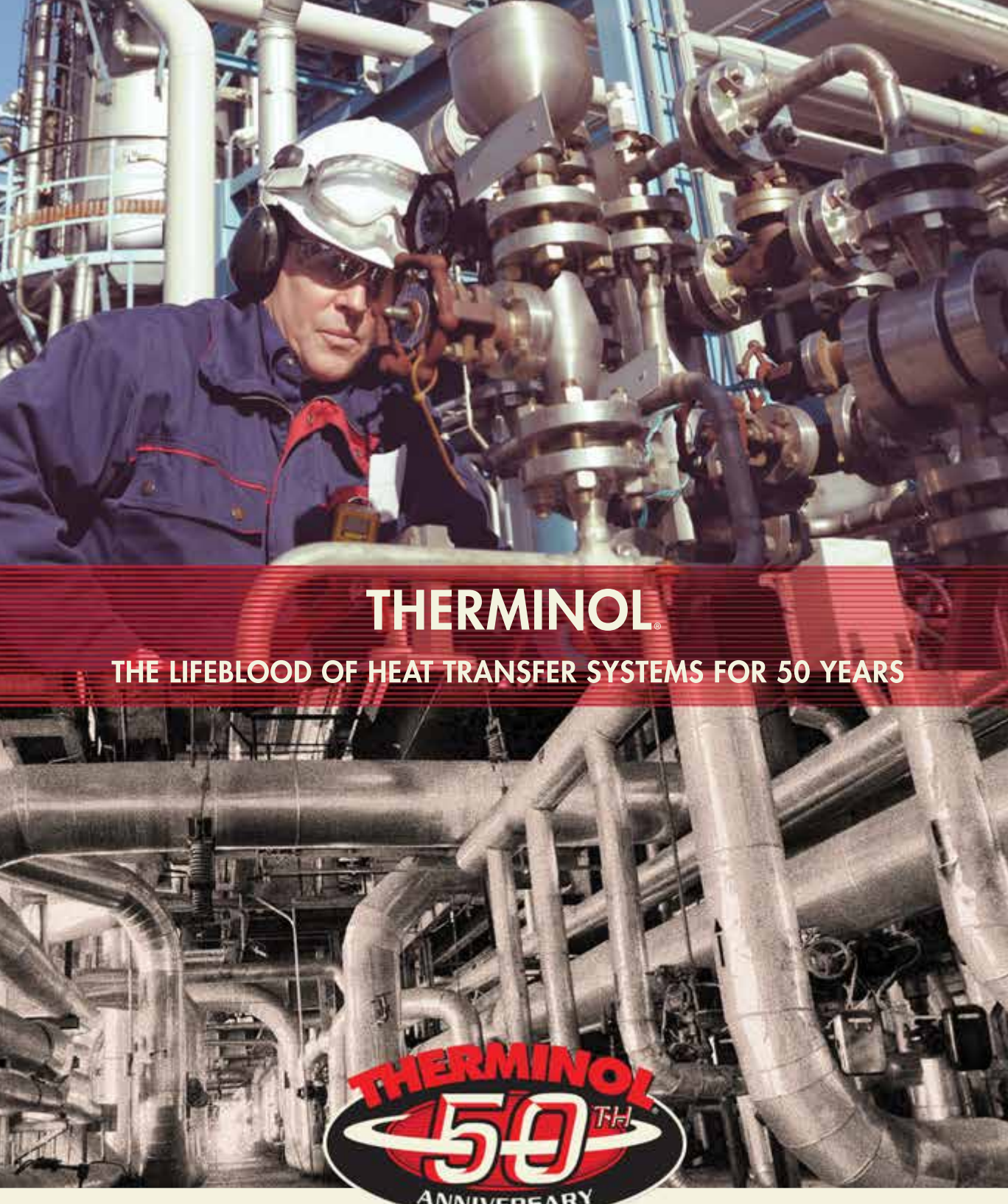

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Keeping the water flowing

Currently, there are around 13,000 desalination plants in operation or under construction in 150 countries, according to the Institution of Chemical Engineers (IChemE; Rugby, U.K.; www.icheme.org). A number of these plants are in, or are planned for, locations that might surprise some of us. In the U.S., the Carlsbad Desalination Project (California; www.carlsbaddesal.com), described as the largest seawater desalination plant in North America, is expected to provide 50 million gal/d of desalinated seawater to San Diego County. The plant is scheduled to start up in 2016. IChemE predicts that by 2050, desalination plants could become common on U.K. coastlines, and by that time, the number of desalination plants across the world is expected to more than double as population growth and other factors place an ever increasing demand on water supply.

By now, it is no surprise to anyone reading these pages that there is a growing focus on sustaining our global water supply. Researchers and engineers are working on ways to improve water and wastewater treatment processes, including desalination technologies to increase the freshwater supply. Some of the latest advances can be found in *Chemical Engineering*'s Chementator section. In April, for example, we reported on work being done at the Lawrence Livermore National Laboratory (LLNL, Livermore, Calif.; www.llnl.gov) on capacitive desalination (A new way to desalt water without using RO or distillation, *Chem. Eng.*, p. 11, April 2013). And researchers from the University of Texas at Austin (www.utexas.edu) and the University of Marburg (Germany; www.uni-marburg.de) are developing a process, called electrochemically mediated seawater desalination, that promises to be an inexpensive way to desalinate small volumes of seawater (Desalination, *Chem. Eng.*, p. 13, August 2013). In a recent press release, IChemE quotes Martin Currie, a member of IChemE's Water Special Interest Group and independent water quality and treatment consultant with Aqueum, as saying, "Globally, water scarcity is such a critical issue, that sustainable desalination is one of the most important areas in which chemical engineers are safeguarding our futures."

Meanwhile, market experts are predicting big opportunities for suppliers to water treatment applications. By aggregating forecasts from several of its water-related reports, the McIlvaine Company (Northfield, Ill.; www.mcilvainecompany.com) concludes that about $2.7 billion will be spent on the membrane portion of desalination investments this year and the rest of the $8 billion expected to be spent on membrane systems will be on related equipment, such as valves, pumps, piping and other filtration equipment. And, according to the ARC Advisory Group (Dedham, Mass.; www.arcweb.com) the water and wastewater industry presents one of the largest opportunities for automation businesses over the next 20 years.

The focus on water and wastewater extends to all applications including both municipal and industrial needs. In fact, these two applications are not mutually exclusive. As the chemical process industries (CPI) strive to limit their water use, and look for more efficient ways to treat and reuse wastewaters, they are also looking at treated municipal water as a water source. Several archived articles in *Chemical Engineering* go into these aspects in more detail. See, for example, Water Reuse and Conservation in the CPI, pp. 44–50, September 2008 (www.che.com/technical_and_practical/4171.html).

And, for more insight into how difficult-to-treat CPI wastewaters are evaluated and treated, see our cover story in this month's issue. ■

Dorothy Lozowski, Editor in Chief

Winner of Eight Jesse H. Neal Awards for Editorial Excellence

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Letters

Field Device Tools gain acceptance

The SAC (Standardization Administration of the People's Republic of China) has announced the official approval of the FDT [Field Device Tool] standard as the China National Standard GB/T 29618, clearing the way for further, broad deployment of the FDT standard throughout China in all industrial and governmental control projects.

The FDT standard is already approved as the IEC 62453 standard as well as the ISA/ANSI 102 standard. This latest approval as the China GB/T 29618 standard now enables multinational companies to deploy the standard in their automation platform on a global scope with assurance of acceptance by all major governing standards bodies.

The FDT standard is freely available for use by any industry supplier or end user without license or royalty. The FDT standard is maintained and advanced by the member companies of the international non-profit FDT Group based in Jodoigne, Belgium.

FDT Group
www.fdtgroup.org

WirelessHART seminars announced

Free, vendor-neutral educational seminars on understanding and using WirelessHART technology in the plant environment are being offered by the HART Communication Foundation in the following locations on the dates as specified:

- Mobile, Ala., October 22, 2013 — 8:00 a.m. to 4:30 p.m.
- New Orleans, La., October 24, 2013 — 8:00 a.m. to 4:30 p.m.

The seminars include real-world examples of plant applications, and live demonstrations of interoperability. Details and registration can be obtained via the website: www.wirelesshart.hartcomm.org

HART Communication Foundation
www.hartcomm.org.

Editor's Note: For more information on digital integration technologies, see Understanding FDI [Field Device Integration], *Chem. Eng.*, pp. 36–39, June 2013.

Do you have —

- Ideas to air?
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If so — Send them, for our Letters column, to

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Calendar

NORTH AMERICA

2013 Gasification Technologies Conference. Gasification Technologies Council (Arlington, Va.). Phone: 703-276-0110; Web: gasification.org
Colorado Springs, Colo. **Oct. 13–16**

International Water Conference. Engineers' Soc. of Western Pennsylvania (Pittsburgh, Pa.). Phone: 412-261-0710, ext. 13; Web: eswp.com/water
Orlando, Fla. **Oct. 17–21**

Oil & Gas Applications: Electrical Grounding Techniques. The Electricity Forum (Pickering, Ont.). Phone: 905-686-1040; Web: electricityforum.com
Edmonton, Alta. **Oct. 23–24**

2013 IEEE West Coast Cement Industry Technical Meeting. Institute of Electrical and Electronics Engineers (IEEE; New York). Phone: 610-573-9389; Web: ieee.org
Victorville, Calif. **Oct. 24**

Lightning Protection Systems Training. The Electricity Forum (Pickering, Ont.). Phone: 905-686-1040; Web: electricityforum.com
Toronto, Ont. **Nov. 1**

Process Expo: Food and Beverage Processing Equipment and Technologies. Messe Düsseldorf (Chicago, Ill.) Phone: 312-781-5185; Web: mdna.com
Chicago, Ill. **Nov. 3–6**

Refining & Petrochemical Wastewater Reclamation Course. University of New Orleans (New Orleans, La.) and Refinery Water Engineering Assoc. (Nederland, Tex.) Phone: 409-548-4661; Web: refinerywater.org
Chicago, Ill. **Nov. 3–6**

2013 Chem Show, 55th CPI Exposition and the AIChE Northeast Manufacturing Conference. International Expo Co. (Westport, Conn.). Phone: 203-221-9232; Web: chemshow.com
New York, N.Y. **Dec. 10–12**

5th Annual World Refining Technology & Shale Processing Summit 2013. Cerebral Business Research Pvt. Ltd. (New Delhi, India). Phone: +91-11-4175-1011; Web: cerebralbusiness.com/wrts
Houston **Dec. 4–5**

The Electric Motor Forum. The Electricity Forum (Pickering, Ont.). Phone: 905-686-1040;

Web: electricityforum.com
Edmonton, Alta. **Dec. 5–6**
Toronto, Ont. **Dec. 9–10**

EUROPE

K 2013: International Trade Fair for Plastics and Rubber. Messe Düsseldorf GmbH (Düsseldorf, Germany). Phone: +49-211-45-60-7611; Web: k-online.de
Düsseldorf, Germany **Oct. 16–23**

PPE 2013 Training: Elastomer Technology & Seal Design for the Critical Sealing Applications. Precision Polymer Engineering Ltd. (Blackburn, U.K.). Phone: +44-1254-295400; Web: idexcorp.com
Blackburn, U.K. **Nov. 6–7**

Adhesion and Adhesives for Converters (Europe). Assn. of International Metallizers, Coaters and Laiminators (AIMCAL; Fort Mill, S.C.). Phone: 803-948-9470; Web: aimcal.org
Brussels, Belgium **Nov. 6–7**

Introduction to Foundation Fieldbus. Fieldbus Foundation (Austin, Tex.). Phone: 512-794-8890; Web: fieldbus.org
Frankfurt am Main, Germany **Nov. 12**

Advanced Principles of Foundation Fieldbus. Fieldbus Foundation (Austin, Tex.). Phone: 512-794-8890; Web: fieldbus.org
Frankfurt am Main, Germany **Nov. 13–15**

Corrosion Event 2013: Bring on the Heat. Dechema e.V. (Frankfurt am Main). Phone: +49-69-7564-278; Web: dechema.de
Frankfurt am Main, Germany **Nov. 14–15**

ASIA & ELSEWHERE

In-Cosmetics Asia. Reed Exhibitions (Surrey, U.K.). Phone: +44-20-8271-2122; Web: in-cosmeticsasia.com
Bangkok, Thailand **Oct. 29–31**

International Pumps, Valves and Systems Conference 2013. Orbitz Exhibitions (Mumbai, India). Phone: +91-24-102-801; Web: ipvs.in
Coimbatore, Tamil Nadu, India **Dec. 5–7**

GPCA Sustainability Conference. Gulf Petrochemicals & Chemicals Assn. (Dubai, UAE). Phone: 971-4-451-06-66; Web: gpcasustainability.com/
Dubai, UAE **Dec. 17–19** ■

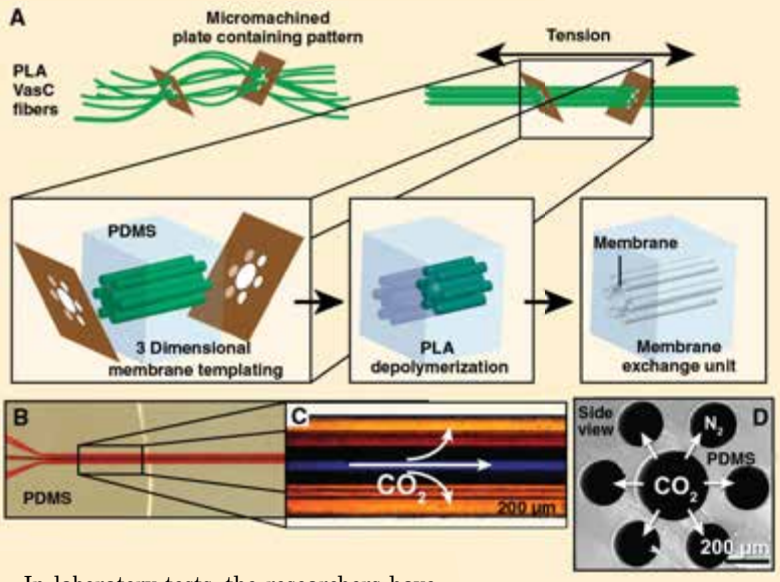
Suzanne Shelley

A 'new' concept for CO_2 capture: birds' lungs

Researchers at the University of California Irvine (UCI, Irvine CA; www.chem.uci.edu) have taken a cue from nature in devising a way to remove carbon dioxide from fluegas. They are developing a synthetic membrane based on the design and function of birds' lungs.

"Birds' lungs are the most efficient mass exchangers in nature and have one of the highest specific surface areas known," says Aaron Esser-Kahn, an assistant chemistry professor. The reason, he adds, is that the lungs are rigid and push gas continuously through thousands of microscopic pores. "They have larger tubes hierarchically connected to smaller tubes, which allows them to maximize surface area while minimizing pressure," he says. "Overall, there are three levels of hierarchy within the lung."

The researchers make the membrane by stretching polylactic acid fibers of two different diameters (100 µm and 300 µm) between two brass plate headers (diagram). The use of two diameters allows a tighter and more efficient pack. This assembly is put into a mold, which is then filled with liquid polydimethylsiloxane (PDMS). After the PDMS sets, the module is heated to about 200°C in a modest vacuum to depolymerize the fibers, resulting in a structure similar to a shell-and-tube heat exchanger.



In laboratory tests, the researchers have flowed CO_2 through the large-diameter channels while feeding monoethanolamine (MEA) countercurrently through the smaller ones. The CO_2 diffuses through the membrane and is carried away by the MEA. Esser-Kahn says MEA is used for convenience, but a commercial unit could use another carrier gas. So far, the mass transfer is below that of commercial hollow-fiber membranes. However, Esser-Kahn says the tests have proved the concept and he expects to increase the specific surface area by creating finer capillaries.

New approach for biobutanol reaches 'lab-pilot' scale

A continuous fermentation process for making biologically derived butanol from a variety of sugar feedstocks is operating at what developers call "lab-pilot" scale, producing 2.5 liters per day. Engineering studies conducted by the research team forecast that it could be produced for the same cost as existing sugar-based bioethanol processes.

The technology developer, Optinol Inc. (San Francisco, Calif.; www.optinol.com), estimated capital and operating costs for commercial-scale manufacturing using its biobutanol process and concluded that it is feasible to produce biobutanol "at cost parity with ethanol."

Optinol has built its process around a robust, naturally occurring strain of *Clostridium* bacteria that converts a range of feedstocks, including sugarcane juice, corn starch, molasses, cellulosic sugars and others, into butanol at high conversion rates. "One of the challenges for genetically modified organisms [producing bio-based chemicals] is that they evolve quickly, and can lose the genetic features that were engineered into them," explains Optinol founder and interim CEO Jack Oswald. "Instead of engineering a bug to fit a process, we took the approach of engineering a production system tailored to the organism."

The company operates banks of inexpensive fermentation columns that contain a cell-growth matrix on which the microbes thrive. The sugar feed is continuously flowed through the columns, where it is converted to butanol. The immobilized-cell columns are followed by a low-cost extrac-

(*Continues on p. 14*)

Strength with stress

Shear forces usually break bonds in polymer materials, but a research team at Duke University (Durham, N.C.; www.duke.edu) has demonstrated for the first time synthetic polymers capable of forming new bonds in the presence of shear forces that would normally break down polymer chains. Termed activated remodeling via mechanochemistry (ARM), the concept depends on a mechanically active dibromocyclopropane moiety that is embedded within a polybutadiene backbone. The dibromocyclopropane ring opens as a result of mechanical stress, forming a 2,3 dibromoalkene product that is susceptible to nucleophilic substitution. This chemistry provides the basis for remodeling and potential self-strengthening or self-repair through covalent cross-linking. The Duke team's results raise "intriguing possibilities of localized mechanochemical self-strengthening to 'at-risk' regions within a load-bearing material," the authors state.

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

Control particle size and morphology with this technique

Lactose has been widely used as a pharmaceutical excipient, where the size and morphology of the particles of lactose significantly affect the functionality of the resultant drug product. Lactose particles produced by various methods exhibit various morphologies, such as spherical amorphous particles, or lactose crystals with tomahawk or sharp and fine morphology. To date, however, there is no report in which a single process can be manipulated to produce both types of morphology, according to a team from Monash University (Melbourne, Australia; www.monash.edu.au). Together with colleagues from Xiamen University (Xiamen) and Soochow University (Suzhou, both China), the team has developed a technique, called antisolvent vapor precipitation (AVP), which can be controlled to produce ultra-fine lactose particles of uniform size, with spiky crystalline morphology or spherical amorphous morphology.

The method is expected to improve the efficiency of powder pulmonary-drug delivery, as for example in the case of asthma inhalers. With current inhaler designs, a large portion of medication propelled into a patient's throat remains there, and only a fraction reaches the lower regions of the lungs, says team member Meng Wai Woo, of Monash's Dept. of Chemical Engineering.

The underlying principle of the technique is liquid antisolvent precipitation. However, instead of large bulk liquid, the AVP technique introduces a single aqueous droplet with dissolved lactose into a stream of convective ethanol vapor. Precipitation is induced when the ethanol is absorbed into the droplet at a different degree and rate of oversaturation.

The researchers have been exploring the possibility of producing precipitated particles from atomized droplets in spray systems. They found that the AVP method enables hundreds of 1–3-µm size excipient particles to be produced from a single, relatively large droplet (about 1,200 µm). The team is now testing its method on another dairy product (whey) and on protein-based medicines. It is also building a demonstration unit to be completed later this year.

Scaleup for a CO_2 mineralization process

A pilot plant will be established at the University of Newcastle (Newcastle, Australia; www.newcastle.edu.au) to test a new technology for the sequestration of CO_2 through mineral carbonation — the reaction with magnesium silicate minerals, such as serpentine, to form mineral carbonates. Mineral carbonation mimics and accelerates the Earth's natural carbon-sink mechanism by combining CO_2 with low-grade minerals to create inert carbonates similar to antacids and baking soda. In the mineral carbonation process, basic rock such as serpentinite is mined, crushed, heated and then mixed with water and pressurized with CO_2 to speed up the natural carbonation reaction, which forms stable magnesium carbonate powder and sand.

The project will be carried out by Mineral Carbonation International (MCi), a joint venture of Newcastle Innovation (the University of Newcastle's technology transfer company); Orica Ltd. (formerly ICI Australia; Melbourne; www.orica.com); and a private investor, the GreenMag Group. The four-year project — funded by the Australian and New South Wales governments and Orica — will be carried out by a multidisciplinary team of researchers led by Orica's Geoff Brent, and professors Bogdan Dlugogorski and Eric Kennedy of the University of Newcastle.

Mineral carbonation as a route to sequester CO_2 has been proposed as early as 1990. The Albany Research Center (ARC; Albany, Ore.) has demonstrated the technically feasible routes for mineral carbonation based on high-pressure aqueous systems. However, according to Brent, the economic viability of these processes has not yet been established. Brent says the ARC did not consider pretreatment via direct thermal activation in a fuel-fired furnace, nor did it include any heat recovery from the exothermic carbonation reaction, both of which could offer significant reduction in net processing costs. Improvements in reaction rates and conversions, as well as optimization of energy utilization via process integration are required, says Brent.

MCi's project will develop a process for direct gas-fired thermal activation of serpentinite ore followed by supercritical carbonation using the ARC process. The project team says the direct use of thermal heat, coupled to partial dehydroxylation and the use of lower CO_2-intensive fuel presents a practical, cost-effective option for serpentine activation.

Purifying aromatics

Last month, BASF's Catalyst Div. (Iselin, N.J.; www.catalysts.basf.com) introduced F-24X, the company's newest catalyst and adsorbent for aromatic purification. F-24-X — a drop-in replacement for its predecessor F-24 — is said to improve process economics through extended life and shorten startup time through lower moisture. The catalyst is used in fixed-bed columns for the purification of benzene, xylenes, cumene, kerosene, jet fuel and other petrochemical and petroleum process streams.

Textile catalyst support

A technique for immobilizing organic catalysts onto textiles has been developed by researchers at the Max-Planck Institüt für Kohlenforschung (Mülhein an der Ruhr; www.kofo.mpi.de), in collaboration with colleagues at the German Textile Research Center (Krefeld, both Germany) and Sungkyunkwan University (Suwon, South Korea). Such functionalized textiles are expected to eliminate the separation step needed for reactions involving homogeneous catalysts, in which the organic acids are normally used in the dissolved state.

The catalytic textiles are made by attaching the catalyst to nylon fibers, followed by irradiation with ultraviolet light for 5 min. The fibers can then be interwoven to form a fabric. The fabric is said to provide a larger surface area compared to alternative immobilization supports, such as plastic spheres or foils.

Three different organic catalysts were tested: dimethylaminopyridine (DMPA; a base), a sulfonic acid, and a catalyst that acts as both acid and a base. All three catalysts converted around 90% of the substrates into the desired products. The amphoteric catalyst — important for performing chiral reactions — also achieved an optical purity of more than 95%.

Hard metal

A new hard metal and a process for manufacturing it have been developed by VTT Technical Research Center of Finland

(*Continues on p. 14*)

A new catalyst promises to cut the cost of the Fischer-Tropsch process

When coal-derived synthesis gas (syngas) is converted to liquid fuel by the Fischer-Tropsch (F-T) process, the initial product is mostly straight-chain waxy paraffins that can be upgraded by hydroprocessing to obtain diesel fuel and naphtha, which are used for gasoline blending. Only about 16% of the F-T plant output falls directly into the naphtha range, according to TDA Research Inc. (Wheat Ridge, Colo.; www.tda.com).

TDA is developing a new F-T catalyst that has achieved 68% selectivity in the naphtha range in bench-scale tests, says Ambalavanan Jayaraman, a senior engineer with TDA. The main advantage is a reduction in the number of process steps, which is expected to cut the cost of liquid fuels production by about $4/bbl from those of conventional F-T processes.

F-T conversion typically employs a cobalt-based catalyst in a slurry-phase or fixed-bed reactor. TDA's process uses a site-selective catalyst of transition metals that controls the hydrocarbon chain length to the naphtha range. Jayaraman says the process conditions are similar to those of conventional F-T reactors: 250–350°C and 300–500 psig. The catalyst can be used either in a slurry or a fixed-bed mode, he says, and a commercial plant would probably use a slurry bubble column.

These resins make tastier orange juice

A process from Dow Water & Process Solutions (DW&PS; Edina, Minn.; www.dowwaterandprocess.com) uses a unique adsorbent resin to improve the taste of orange juice. Amberlite FPX66 is a macroreticular, non-functionalized adsorbent resin with a pore structure designed to capture a variety of target molecules. In the case of orange juice, this resin removes limonin, a highly bitter compound. Limonic acid, present in all oranges, naturally esterifies over time to limonin, which resides in oranges' membrane structure.

Using a combination of ultrafiltration and Amberlite's polymeric aromatic adsorbent, orange juice is de-bittered by selectively removing limonin, while still maintaining the juice's other flavor components. Amberlite beads have a high surface area, and the pore structure provides selective capture of target molecules. The large surface area also means that throughput is not limited by the adsorbent's capacity. Amberlite beads have a polymer matrix that provides physical rigidity and thermal stability. These beads can be re-used for hundreds of cycles, so there is significantly less operational waste as compared to the use of powdered activated carbon. An adsorbent resin that is used in typical commercial installations can last up to five years in service before needing to be replaced.

An inexpensive iron catalyst for efficient hydrogenation reactions

The research group of Yasuhiro Uozumi and Yoichi Yamada at Riken (Saitama, Japan; www.riken.jp), in collaboration with professor Audrey Moores of McGill University (Montreal, Que.), has developed a highly efficient catalyst for performing hydrogenation reactions, which are important in the refining of petroleum and oils and fats. Compared with conventional catalysts, which use precious metals costing hundreds of thousands of dollars per kilogram, the new catalyst system is based on inexpensive ($1/kg) and abundant iron.

Uozumi's group had been developing hydrogenation catalysts by depositing nano-sized Pt and Pd particles onto polymer matrices. Now, the researchers applied their deposition technology for nano-sized (5 nm) Fe(0) particles. The nano-Fe is deposited on an amphiphilic polymer resin (polystyrene-polyethylene glycol) with 0.09 mm dia., at a temperature of 180°C. Although insoluble in water and organic solvents, the resin can absorb such liquids sufficiently to act as solvent for the reaction.

The new catalyst worked very efficiently for the hydrogenation of alkenes and alkynes in an ethanol solution, using a flow-type reactor with H_2. A nearly 100% yield was achieved within 1 min., which is almost $1/100^{th}$ the time needed for conventional hydrogenations. Also, the catalyst suffered almost no deterioration due to oxygen or water, which has been a problem with existing catalyst systems. Furthermore, the researchers found that they could use a low-toxic system, such as ethanol- and methanol-water mixtures as reaction medium, thus enabling improved safety.

Riken plans to further develop the Fe-nanoparticle catalyst to enhance its long-term stability, and expects to contribute to the development of a large-scale processing facility with a production capacity of more than several tons per year.

Pelletizing technology for iron ore improves strength and output

Iron ore is traditionally pelletized using the binding agent bentonite to facilitate transport and handling. A new additive for pelletizing iron ore significantly reduces the volume of binding agent required, while improving pellet strength and production output.

Developed by Clariant AG (Muttenz, Switzerland; www.clariant.com), the pelletizing additive is a patented polymer-based binding agent that can reduce the bentonite required by more than 66%, Clariant says. Further, the additive, known as Floticor PA 8000, binds more quickly and improves the pellets' compressive strength and abrasion resistance, which reduces fines waste, the company adds.

In the iron-ore pelletizing process, an agglomeration step collects material from the iron ore cleaning and concentration process and sends the material through pelletizing machines, where the Floticor PA 8000 additive is introduced. The resulting pellets are less susceptible to breakage during handling, Clariant says.

"Among the key advantages of the product is that it binds more quickly than the traditional method, so the residence time in the pelletizer is shorter," explains John Dunne, senior vice president and general manager, Oil & Mining Services. This allows production speeds to be higher and throughput increased, he adds. Further, the additive allows iron ore producers to source materials with higher levels of naturally occurring impurities, such as SiO_2 and Al_2O_3, Dunne says.

The additive product can be dosed into the pelletizing process using conventional machinery, and no processing changes are required for the steel producers. Trials of the additive product in full-plant operations in Brazil and Oman have returned favorable results, Clariant says, and the product is being rolled out worldwide.

BIOBUTANOL (*Continued from p. 11*)

tion system that takes advantage of butanol's natural immiscibility with water and uses fluids that attract the butanol into solution. The end product is then separated with a low-energy distillation process that Oswald calls "straightforward."

The Optinol biobutanol process has been operating at a facility on the campus of Louisiana State University (Baton Rouge, La.; www.lsuagcenter.com/subi) for two years, and the company is working on further development and scaleup.

(*Continued from p. 12*)

(Espoo; www.vtt.fi) and Exote Ltd (Helsinki, both Finland; www.exote-armour.com). The material can be used to replace tungsten carbide, whose global availability is said to be becoming critical. Exote's new material is said to be able to withstand high temperatures and has high strength and durability, making it suitable for the manufacturing of crusher blades, shear cutters and machining tools. It also possesses "excellent" bullet-proofing qualities, making it suitable for protecting vehicles and people. The material's toughness and hardness can be varied to match the desired application through the use of nano additives, says VTT.

Sensitivty boost for SERS

Surface-enhanced Raman spectroscopy (SERS) can be used for detecting environmental pollutants, pharmaceuticals in water and forensic investigations, but until now, the technique has not been widely used due to low signals and reproducibility. Now, a new SERS sensor capable of detecting concentrations of a few femtomoles per liter has been developed by scientists at ETH Zurich (Switzerland; www.ethz.ch) and the Lawrence Livermore National Laboratory (Calif.; www.llnl.gov).

To make the new sensor, a dense forest of carbon nanotubes is grown onto a substrate, and the tips are coated with gold and a dielectric insulating material, hafnium dioxide. It was the introduction of the HfO_2 that led to an increase in the substrate sensitivity by a factor of 100,000. The group is seeking an industrial partner to commercialize the technology, which shows promise for use in portable analyzers.

Bio-hybrid photocatalyst

Scientists from Argonne National Laboratory (Ill.; www.anl.gov) have combined bacteriorhodopsin — a pigment from microorganisms that live in desert salt flats — with semiconductor nanoparticles to create a hybrid photocatalyst that enables TiO_2 to catalyze the water splitting reaction to occur using visible light. The discovery is a step toward green H_2 production. ❑

Solid-catalyst method for breaking down cellulosic biomass cuts costs

Fermenting sugar is at the heart of many bio-based chemical and biofuel processes, but obtaining sugars from cellulosic biomass at low cost is an ongoing challenge. A new process using a reusable solid catalyst is capable of breaking down a wide range of waste biomass into fermentable sugars at costs lower than deriving sugar from corn or sugarcane.

Midori Renewables (Cambridge, Mass.; www.midorirenewables.com), a Flagship VentureLabs company, has developed a biomass-to-sugar process that depends on a polymer catalyst functionalized with ionic species. Consisting of spherical polymers with specially designed functional groups on the surface, the catalyst enables reactions similar to those that break down cellulose biologically, but does not require enzymes, mineral acids or microorganisms.

"We looked at a large number of approaches to breaking down cellulosic biomass, and found that the solid catalyst approach was underexplored and underdeveloped," explains Midori's founder and Chairman Brian Baynes. The company is now able to produce ton-scale amounts of the reusable catalyst and 50–100 kg/h of sugar at its pilot sites.

The conversion process works by using low-grade steam to heat a pre-mixed reaction chamber containing the biomass and catalyst, to about 100°C. Once the cellulose is converted to sugar, the catalyst is filtered out for re-use.

The process is designed to be installed on the front end of an ethanol facility to provide fermentable sugars for further processing. The overall production costs depend on many factors, Baynes says, but the company expects to be able to produce sugar for below $0.10/lb, and possibly as low as a few cents per pound given the right logistics. By comparison, producing sugar from corn and sugarcane costs $0.15–0.20/lb.

Baynes says Midori is in the site-selection and engineering stage of a "commercial demonstration plant" for the process, and expects facility construction to begin in 2014.

Cross-coupling catalyst

A highly active nickel catalyst for performing cross-coupling reactions has been developed by the research group of professor Shu Kobayashi at the University of Tokyo (Japan; www.chem.s.u-tokyo.ac.jp). The researchers were able to immobilize nickel nanoparticles onto a polymer support matrix in such a way to avoid metal leaching and deactivation — two problems that have hampered development up to now. Using the group's polymer-incarceration (PI) technique (*CE*, September 2012, p. 16), they designed N-heterocyclic-carbene precursors as active cross-linking agents within the polymer support matrix.

The Ni-based catalyst system was successfully applied to the Corriu-Lumda-Tamao reaction, which is important for forming C–C bonds. Yields of 68–98% have been observed for a broad range of substrates, and the catalyst system could be recovered and reused several times without loss of activity. ■

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ADVANCING BATTERY MATERIALS

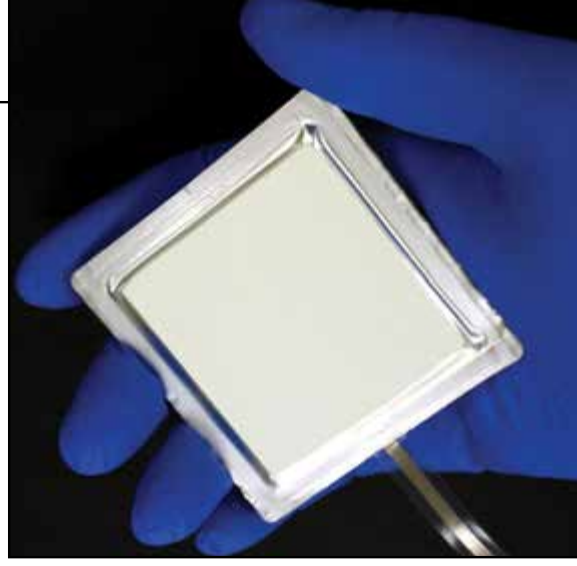


FIGURE 1. The Protected Lithium Electrode (PLE), developed by PolyPlus Battery Co., is an enabling technology for future Li-sulfur batteries

Technology developers seek better performance and lower costs for Li-ion batteries, while others explore what lies beyond

Lithium-ion rechargeable batteries are the technology of choice for powering portable consumer electronics, but limitations remain, especially when using this battery type in large-format applications like the fast-growing electric vehicles sector.

"The four most important challenges for Li-ion batteries are increasing energy density, improving safety, lowering cost and lengthening battery lifetimes," says Elena Shembel, CEO of Enerize Corp. (Coral Springs, Fla.; www.enerize.com), a company that is developing new manufacturing technologies for batteries, supercapacitors and more.

A massive effort is underway on the part of private companies, government laboratories and academic institutions to develop ways to boost Li-ion battery performance, while addressing the safety and cost issues associated with these batteries. Meanwhile, parallel work by other researchers and companies is looking beyond current Li-ion battery technology to alternative lithium-battery chemistries, such as lithium-sulfur and lithium-air batteries. These newer, less developed technologies have theoretical energy characteristics that surpass even the best current technology by a wide margin.

Evolving industry

By almost any measure, the market for advanced batteries is growing, especially for transportation vehicle and grid-energy storage applications. The Li-ion battery market is $17 billion now, and is expected to grow to $75 billion by 2020, according to Steve Visco, CEO of PolyPlus Battery Co. (Berkeley, Calif.; www.polyplus.com).

Mark Gresser, CEO of Wildcat Discovery Technologies (San Diego, Calif.; www.wildcatdiscovery.com) says, "The battery industry is growing at around 6%/yr, and that growth is expected to continue." Further, batteries will continue to improve, with cost reductions of 8–9% per year, he forecasts.

"The growing number of applications for batteries means that there are many different sets of demands placed on batteries," says Brian Morin, president and COO of Dreamweaver International Inc. (Greenville, S.C.; www.dreamweaverintl.com). What this means is that there is room for a great deal of diversity in battery technology, Morin suggests. "Lots of products will find a home."

Material discovery

Among the challenges for battery manufacturers is identifying new materials that can improve performance and cost, and also evaluating how those new materials work in a battery cell system. Wildcat Discovery Technologies is applying a high-throughput approach to the discovery of new battery materials. The company's platform allows a large number of electrochemically active materials to be synthesized quickly and formulated under a variety of conditions. The Wildcat system then systematically tests the materials in complete electrochemical cells.

Wildcat's Gresser says "we take a parallel approach to discovery that can test many combinations of active materials and binders simultaneously." The company's high-throughput synthesis platform allows for the synthesis of a wide range of pertinent material types, including oxides, phosphates, intermetallics, complex hydrides and p-block materials, the company says. Further, Wildcat's tools allow precise control of particle size and morphology. After synthesis, the materials are cast into films and undergo a calcination step before cell assembly.

The company has also developed materials-handling tools that allow each candidate to be formulated into multiple electrodes in which the amounts and types of conductive additives, binders, electrolyte and other additives are varied. Finally, each formulated electrode is assembled directly into a complete battery cell.

Wildcat has a proprietary, massively parallel electrochemical assay capable of measuring a host of general electrical properties, such as energy density, power, performance at different temperatures, gas evolution during operation and coulombic potential.

"In addition to carrying out testing and discovery projects for battery industry clients, we are also developing our own intellectual property, which we hope to license," Gresser says.

EnerG2 Technologies Inc. (Seattle, Wash.; www.energ2.com) is also working on tools to improve anode and

cathode materials for energy storage applications, including Li-ion batteries. Its platform allows the creation of customized carbon materials with highly tuned properties. The company's intellectual property is based on an ability to create material properties that can only be achieved by careful manipulation of polymer structure at a molecular level. The engineered polymers are thermally carbonized to produce carbonaceous materials with tailored properties, including pore size, pore structure, distribution and several others.

"We're laying out a physical and chemical landscape for electrochemistry to occur," says Rick Luebbe, EnerG2's CEO, so the characteristics of the carbon electrode material can be matched to a given application. The company's Carbon Technology Platform has been executed at commercial scale at a facility in Albany, Oregon where Li-ion electrode materials will be produced beginning in 2014 (Figure 2).

FIGURE 2. Energ2 has commercialized a process for making tailored carbon materials for energy storage applications

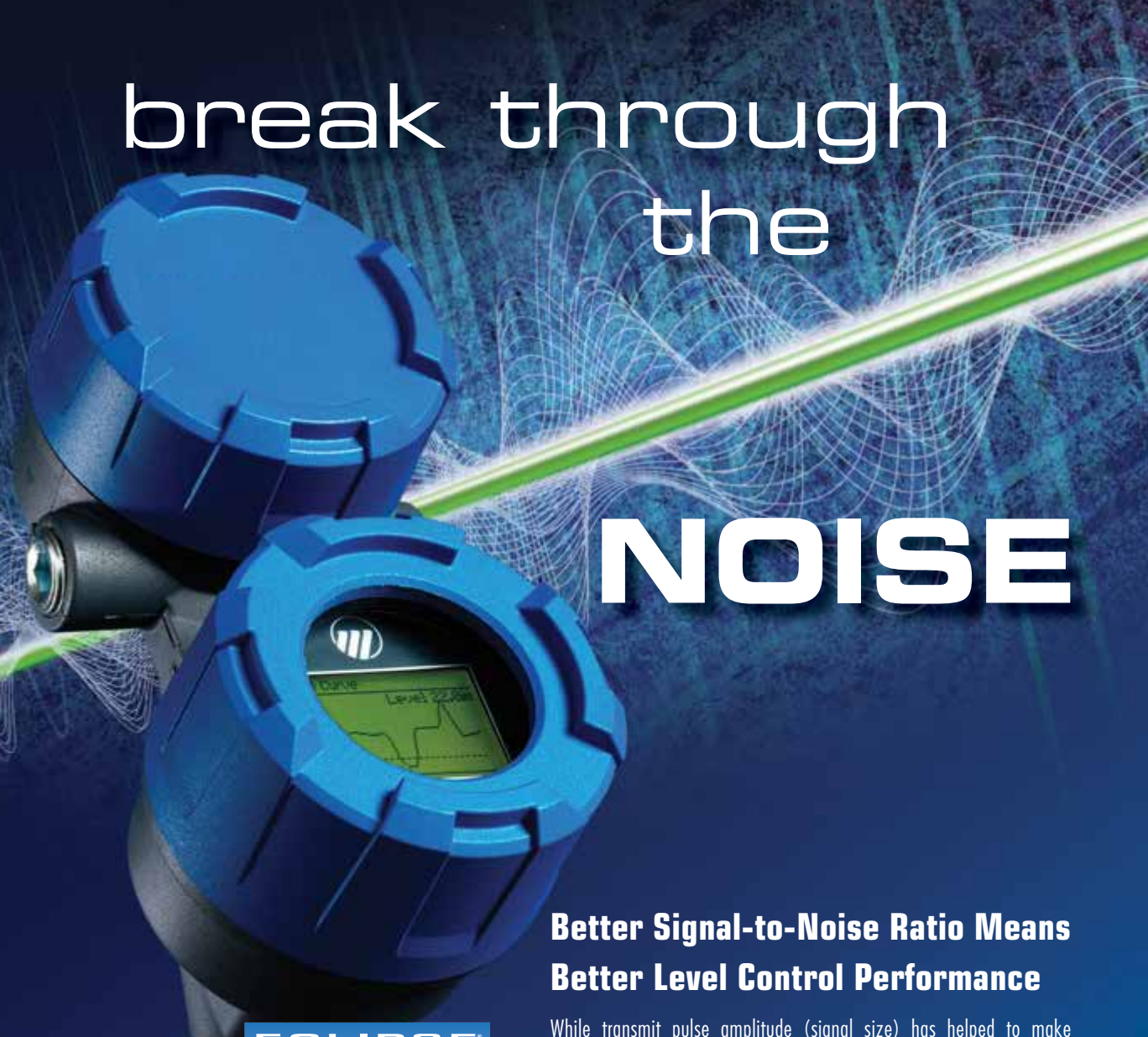
Silicon-containing anodes

A major focus of material discovery and development efforts over the last year has been improving anode materials for next-generation lithium batteries. One promising approach for increasing energy density is incorporating silicon into the anode. Silicon is regarded as one of the most promising anode materials for lithium-ion batteries because its theoretical specific energy capacity is higher than that of the graphite anodes used today.

"Silicon-based anodes theoretically offer as much as a ten-fold capacity improvement over graphite, but silicon-based anodes have so far not been stable enough for real-world commercial use," explains Jungbing Yang, an engineer with California Lithium Battery Inc. (CalBattery; Los Angeles, Calif.; www.clbattery.com), a company formed to commercialize technology first explored by Argonne National Laboratory (Argonne, Ill.; www.anl.gov).

CalBattery's Yang explains that a key objective for making silicon-graphite composite anodes is to distribute the silicon into the graphite uniformly and to stabilize the silicon inside to avoid breakdown of the electrode. CalBattery has devised a specialized gas-phase process that embeds silicon into graphene (single-layered graphite) electrodes to boost its energy density when used with a high-capacitance cathode. As a raw material, the process uses effluent chlorosilane gas, which

break through the NOISE



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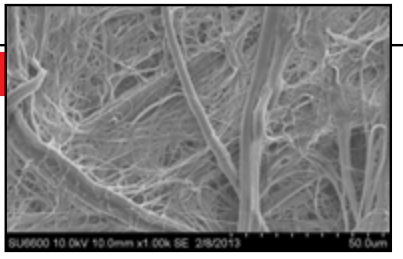

FIGURE 3. A battery separator technology from Dreamweaver International combines micro- and nanoscale filaments in a wet-laid non-woven manufcaturing process

can be obtained from the production of polysilicon for solar photovoltaic cells.

CalBattery has worked with Argonne and other facilities to develop the new anode material to work in a full Li-ion battery with multiple cathode and electrolyte materials. CalBattery says its initial results suggest that the advanced anode material could eventually replace conventional graphite-based anode materials used in most Li-ion batteries manufactured today.

Electrolytes

Electrochemical cells function very much as an interconnected system, where the properties and characteristics of each component affect all the others. The higher voltages enabled by new electrode materials require electrolytes that can handle them. One company active in this area is Enerize Corp. CEO Elena Shembel says her company has obtained a host of issued and pending patents over the last several years surrounding solid inorganic electrolytes and equipment to manufacture solid-state batteries based on this electrolyte and proprietary electrode materials.

The company's solid electrolyte can operate at ambient temperatures as well as at high temperatures (up to 220°C). "Current liquid and polymer electrolytes for Li-ion batteries are only safely operable to 70°C, since the organic material used in non-aqueous electrolytes is flammable and easily ignited," Shembel explains, so existing batteries with organic electrolytes require elaborate, and therefore expensive, systems to keep temperatures low. This is one reason why Li-ion batteries for electric vehicles remain so expensive. "The solid inorganic electrolyte operates safely at higher temperature, reducing the requirements and costs of a cooling system," she says.

The company is developing materials and technology for full-scale production of solid electrolytes and electrodes, as well as equipment for thin-film deposition for battery production.

Battery separators

In addition to electrodes and electrolytes, improving battery performance and safety, while lowering cost, depends also on the membrane separators through which ions pass. One company that has made considerable headway in improving separators for large-format batteries is Dreamweaver.

Dreamweaver's Brian Morin says that although the current polyethylene (PE) and polypropylene (PP) battery membrane-separator technol-

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ogies have worked for 20 years, manufacturing these materials, especially with the high degree of uniformity required, is difficult. "It's a slow, multistep process to make [separators], so the capital cost is very high," Morin says, adding that PE and PP separators have low thermal stability.

Dreamweaver's new battery separator has a proprietary chemical composition that is stable up to 200°C (50–75°C higher than current PE and PP membranes) and is easier to manufacture. The material has a high-temperature backbone that accepts liquids well and has controlled porosity, Morin says. This allows for a high-power battery.

Further, "the separators are made via a wet-laid, nonwoven process that combines both nanoscale and microscale filaments," Morin explains (Figure 3). The capital hardware for the process already exists, so the company's cost structure is "an order of magnitude lower" than for existing separators, he says.

Another company seeking to improve battery separators using a different approach is Madico Inc. (Woburn, Mass.; www.madico.com). Madico R&D manager Dave Avison, explains that the role of a battery separator is to provide maximum electrical insulation, while allowing the fastest and easiest ionic conductivity. "But those two objectives are essentially at odds with each other, so it's a difficult challenge."

Madico's approach is to use small particles of a specific crystal form of the ceramic material baumite (alpha-aluminum oxide, AlO_3) bound within an organic polymer matrix. The crystal form of AlO_3 has specific properties with regard to ionic conduction, and the organic matrix has a higher thermal stability than current polyolefin separators. A key characteristic of Madico's separator is its ability to have its properties tailored easily by adjusting various parameters. "There are a lot of dials we can turn to adjust the properties of the baumite surface and other things," says Avison.

Madico has also thought about the production process, developing a solvent-based coating process with a roll-to-roll manufacturing capability similar to methods used in paper manufacturing. "This widely used process technology gives us the ability to make separators at wide widths and fast line speeds, and without added production steps," says Avison. "We can make 72-in.-wide rolls at 100–500 ft/min."

Madico's free-standing separator will be introduced in late 2014, Avison says, with a median pore size of 30–50 nm and a tight Gaussian size distribution.

New lithium chemistries

Although Li-ion batteries will continue to play a large role in many applications, they have inherent limitations that are pushing researchers to explore alternative lithium chemistries, such as lithium-sulfur and lithium-air batteries, where lithium metal is used

as the anode and either carbon-coated sulfur or oxygen from surrounding air, respectively, are the cathodes. In Li-ion batteries, the ions are intercalated into the electrode materials, rather than chemically bound.

To achieve batteries with the energy density to compete head-to-head on performance with fossil fuels, batteries would need to reach much higher energy densities than currently available. Even if Li-ion batteries were improved to twice today's capabilities, they would still only reach 400 Wh/kg. In contrast, the theoretical energy density for a Li-sulfur battery is 2,500 Wh/kg at an average voltage of 2V, while Li-air (using O_2 as the cathode) is 10 times that of current Li-ion batteries. And with cheap, abundant substances as battery components, their costs are also potentially lower.

"For power-grid-storage and electric-vehicle applications, batteries are very cost-sensitive and very cycle-sensitive," says Steve Visco, CEO of PolyPlus Battery Co. (Berkeley, Calif.; www.polyplus.com). "So the industry is ripe for a step-change technology that lowers costs and improves cycle performance."

Compared to Li-ion batteries, using cheap and abundant sulfur as the active cathode material in Li-S batteries gives an order-of-magnitude higher energy density, but two technical hurdles have prevented their development. One challenge has been the so-called polysulfide shuttle, wherein soluble intermediate Li-S_x species diffuse through the separator from the cathode to the anode and lead to self-discharge of the battery. The second is the poor solubility of Li_2S (the final discharge product) in the electrolyte, which forms deposits on the cathode material and blocks diffusion, or can precipitate out of solution and become electrochemically inaccessible.

PolyPlus, a company spun out of work at Lawrence Berkeley National Laboratory (Berkeley, Calif.; www.lbl.gov) in 1990, has developed patented solutions to these problems, helping to enable future lithium-sulfur batteries. The company's Protected Lithium Electrode (PLE) is a proprietary lithium electrode that is encased with a solid ceramic electrolyte and a patented seal (Figure 1). The encapsulation enables high conductivity for Li^+ ions but is impervious to liquids and gases. PolyPlus has built a fully operational pilot production line to manufacture the protected lithium electrode.

PolyPlus is improving the manufacturing technology for the PLE, and is working toward a prototype Li-S battery. The prototype will be designed to couple low-cost sulfur with low-cost water-based electrolytes. PolyPlus is also developing single-use Li-seawater and Li-air batteries for specific applications. ■

Scott Jenkins

Editor's note: For additional information on advanced battery materials, please see the extended online version of this article at www.che.com.

A VALVE FOR EVERY APPLICATION

Georg Fischer Piping Systems

FIGURE 1. The New Generation diaphragm valve provides safety, efficiency and simplicity via a central union nut that offers a non-corrosive connection, homogeneous temperature behavior, an even surface pressure, and a high-pressure rating up to 240 psi (for water use only)

CPI applications demand that valves stand up to harsh environments and prevent fugitive emissions. Manufacturers discuss the latest products that can help

Let's face it, valves may not be the most glamorous piece of equipment in a chemical process industries (CPI) facility, but no plant can function without them. In addition, multiple challenges and issues specific to the chemical processing industry affect valves and valve performance. For these reasons, selecting the right valve — one that will stand up to the rigors and demands of the chemical processing industry — is of the utmost importance. Here, valve manufacturers discuss their latest offerings and how improvements in design and materials can really make a difference.

Extreme conditions

"The piping systems in chemical production are subjected to extreme conditions," says Thomas Kussner, product manager for diaphragm valves with Georg Fischer Piping Systems (Schaffhausen, Switzerland; www.gfps.com). "Aggressive substances need to be transported and processed, which places high demands on system solutions."

He adds that besides being very reliable, valves for the CPI should offer the following:

- Maximum corrosion protection
- Suitable materials for outstanding chemical resistance
- Safe and best practice-complete solutions
- Reduced maintenance costs
- Simple, but high-quality installations
- Energy-saving systems with optimized flow

To address corrosion protection and the other issues related to the CPI's aggressive processes, the new Generation Diaphragm Valve from GF Piping Systems (Figure 1) offers non-corrosive connections. Instead of the commonly used four metal screws, the new diaphragm valve has a central plastic housing nut. This non-corrosive connection is characterized by homogeneous temperature behavior, an even surface pressure, and high-pressure rating up to 240 psi (for water use only).

"What's the direct advantage of this?" asks Kussner. "The corrosion-free connection guarantees homogeneous expansion when exposed to temperature variations, which eliminates the need to retighten the screws."

He adds that aggressive environments can be found everywhere in the CPI, so it is important to know that the right components have been built in. "The principle of the central thread eliminates completely the metal screws, and thus, eliminates the risk of corrosion. Good flow and linear regulation characteristics are basic requirements for efficient and reliable processes in dosing, mixing, filling and bottling of chemicals.

"The big advantage of plastics compared to metals is that there is no electrochemical corrosion," Kussner continues. "In addition to this, plastic is lighter than other materials. Moreover, the outstanding chemical resistance of plastic, especially when conveying highly aggressive or pure media, has a positive impact."

Schubert & Salzer Control Systems

FIGURE 2. In these compact pinch valves, the reduction in cross section is brought about by a plunger acting on one side. Previously, a sleeve section made specially to fit into the cross section had to be used for this. Now, the change in cross section is achieved by a new body design rather than requiring a specially molded sleeve. This has resulted in improvements in flow coefficients

Todd Haberkost from Ladish Valves (Houston; www.ladishvalves.com) adds that the CPI must employ safe, reliable valve products that will consistently perform in the service environment in which they are placed. "We like to say 'the nastier the application, the better,' because our niche is delivering customized products in exotic alloys for the most severe service environments," says Haberkost.

"In the stainless and exotic alloy arena, material trace-ability and quality should be at the forefront of any manufacturer's quality system. In-house ability to verify material chemistry through the use of an X-ray fluorescent gun or spectrometer is a necessity. Additionally, regular testing of material mechanical properties should be performed to verify the vendor's material test certificates.

Crane ChemPharma & Energy

FIGURE 3. The Xomox XLB lined ball valve offers smaller actuators for reduced costs and space and weight savings. It allows installation in space-restricted areas in parallel piping systems and is fully lined with permeation-resistant PFA material as a barrier to corrosion

Ongoing corrosion testing based on published industry standards is also something chemical processors must consider when selecting valves for aggressive environments," notes Haberkost.

To meet the needs of harsh environments, Ladish offers a complete line of corrosion-resistant, stainless-steel, and exotic-alloy gate and globe valves. The globe valves are used for throttling flow control. Shut off is accomplished by moving the disc against the flow stream rather than across it, as in the case with a gate valve. The company's gate valves are suited for water, oil and gas service, as well as a variety of other fluids. They are intended for on-off flow control and should only be used in the fully open or fully closed position. When fully opened, fluid flow through the valves is in a straight line, resulting in minimum pressure drop across the valve. Gate valves are bi-directional and can be used for flow in either direction.

Ladish's globe and gate products are manufactured as full port, with threaded, socket-weld, flanged and butt-weld ends. Pressure classes include 150 through 1500, available in a variety of materials to suit aggressive environments.

Also designing to deal with challenging applications, Schubert & Salzer Control Systems (Ingolstadt, Germany; www.schubert-salzer.com) re-engineered its pinch and pinch control valves (Figure 2) to reliably shut off and control fluids with granular and abrasive particles, as well as viscous, pasty and aggressive media.

The new 7078 pinch and 7079 pinch control valves offer compact construction with a rotating piston actuator, all wetted metal parts made from 1.4435 1.4408 stainless-steel body, FDA-compliant seals for hygienic applications, working pressures up to 6 bar, FDA-compliant sleeve materials made from NBR (nitrile butadiene rubber) or EPDM (ethylene propylene diene monomer), and sleeves with reinforced woven fabric to increase service life.

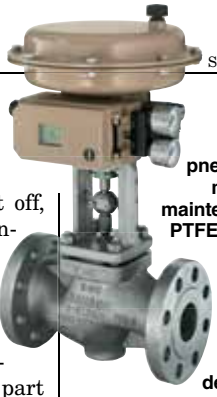
Together with a collet and union nut, a new type of fastener provides a fast, secure and permanently drop-tight connection between the pinch valve and optional connections with female thread welding ends, Tri-Clamp or even adhesive sockets.

Fugitive emissions

Leaks from pressurized process equipment in the chemical processing industry generally occur through valves, pipe connections, mechanical seals or related equipment. "Due to the huge number of potential leak sources at large chemical facilities and the difficulties in detecting and repairing some leaks, fugitive emissions can

be significant," notes Vijay Malik, director of global engineering at Crane ChemPharma & Energy (Cincinnati, Ohio; www.cranechempharma.com).

To assist with this challenge, Crane's Xomox and WTA metallic valves are available in a variety of materials, configurations and multiport models. In most difficult applications, they provide positive shut off, effective fugitive control, low maintenance and long service life. But perhaps the innovation that will most help chemical processors avoid fugitive emission issues is the stem sealing system available on the XLB lined ball valve, part of the Xomox product line (Figure 3).



Samson

FIGURE 4. Type 3241-7 pneumatic control valve with Type 3730-6 electropneumatic positioner offers a modular design, as well as maintenance-free, self-adjusting PTFE V-ring packaging as standard. The patented, zero-emission, multi-layered bellows technology guarantees a minimum of 100,000 full cycles, and the straight-threaded seat design requires no gaskets, cage or other seals

These lined ball valves with lower torque and smaller actuators are fully lined with permeation-resistant PFA (perfluoroalkoxy) material as a barrier to corrosion and are also available in stainless-steel construction to maximize cleanliness and minimize areas where contamination could occur. But it is the innovative sealing system that assists with avoiding fugitive emissions. The sealing system includes the following:

- A latching device that minimizes the possibility of accidental operation
- The body of the joint, which ensures that no parts of the lining can be crushed or deformed because of the forces within the piping system
- A design that will maintain total seal even under extreme thermal cycling
- A pressure-assisted SX seal device that provides the protection against fugitive emissions
- The ability to retain positive control and minimize the danger of stem/ball failures due to liner damage at wear points
- The ability to resist shrinkage and collapse, and permit vacuum applications
- Greater pressure stability at higher temperatures than conventional PTFE

"When valves are closed under pressure, the ball is able to float with the line pressure and pressurize the downstream seat to further enhance the inline seal," says Malik. "However, the stem will tend to tilt and can side load conventional packing, leading to potential wear and eventual leakage. The SX seal in the XLB valve moves in conjunction with the spherical portion of the stem, maintaining a constant seal.

"The body assembly has a metal-to-metal connection that offers resistance against forces that may be created in the pipe work," he continues. "This feature is designed to alleviate deformation and damage to the lining, even under pressure-induced stresses. Also, the body joint sealing is provided with

tape lining overlap, which is especially effective under high internal pressure and temperature variations."

In addition to the valve itself, Haberkost with Ladish says the valve packings are equally important. "One of the most serious technical issues facing the industry today is the control of plant-wide fugitive emissions," he says. "For this reason, we provide low-fugitive-emission graphite packing. With in-house fugitive emission testing, Ladish has the capability to test packing using either methane or helium. Graphite packing brands used by Ladish have been tested to API 622. Further, our ability to manufacture valves to specific customer packing and gasket requirements and test valves in house allows our company to provide optimal fugitive emission solutions."

Mixed bag

Because the chemical processing industry has to consider so many issues, including aggressive environments, fugitive emissions, materials compatibility, safety, and reliability, Markus Guntner, senior product manager with control valves and applications at Samson AG (Frankfurt am Main, Germany; www.samson.de), says a modular valve design is key to satisfying a variety of chemical processing needs. "There are countless types of processes and process media in the chemical industry that call for a variety of different valves," he explains. "Our modular valves can be made from over 20 different materials. As a result, we can offer valves suitable for a variety of process media, as well as pressure and temperature ranges. The control requirements find compliance using variable Cv coefficients, and various seat and plug designs withstand critical flow conditions, such as flashing and cavitations.

"Our Series 240 globe valves cover almost 90% of applications in the chemical industry," he continues. "Theoretically, three billion different valve configurations are possible thanks to the modular design of our valves to provide the ideal solution for any specific control task." (Figure 4)

Guntner also reminds chemical processors that it's not only the actual valve that's important. "Digital positioners with diagnostic functions are increasingly moving to the forefront," he says. "They facilitate start up, monitor the valve in process, and allow for predictive maintenance. These are all factors that increase plant availability."

Nowadays, control valves are complex modular units in the process control loop, which are integrated into process control systems. According to Guntner, this means that to provide the best control solution, valve suppliers not only need expert knowledge in the fields of control and valve technology, but also in electronics and software. ■

Joy LePree

FOCUS ON

Packaging

Dinnissen B.V.

A system to reduce losses when emptying bags

Bags of 10–90 kg typically lose between 0.4 and 1% of the products — often expensive ingredients — due to residues left behind when the bags are emptied, says this company. To reduce losses, the company has developed a new system (photo) for emptying bags. Up to 99.9% of the contents can be removed by the system, which uses vibration-, air-pulse- and suction-based technology. The system is especially suited for processing expensive and contamination-sensitive ingredients. The system is suitable for all types and sizes of bags (10–90 kg) and can be used with products having a wide range of transport characteristics. — *Dinnissen B.V., Sevenum, the Netherlands*
www.dinnissen.nl

Flexicon

Cortec

Lock Inspection Systems

Packing paper that protects against corrosion

Bio Wrap Creped — powered by Nano-VpCI (vapor-phase corrosion inhibiting technology) — is a corrosion-inhibiting paper for protecting metals that are in an enclosed package (photo). This non-toxic, biodegradable crepe paper combines multimetal corrosion protection with the packaging benefits of paper creping, which increases the tensile strength and degree of pliancy. The paper provides cushioning and surface protection for wrapped parts and a "pooling" effect for oiled parts. The paper is effective against aggressive environments, including humidity, SO_2, H_2S and galvanic corrosion from dissimilar metals. It can be used for the protection of products for storage and shipment, as end enclosures for shipping tubes, insert paper for recess areas in large packages and as sheet liners or separators between products. — *Cortec Corp., St. Paul, Minn.*
www.cortecvci.com

Integrate this tubular conveyor anywhere up- or down-stream

The new Flexi-Disc line of Tubular Cable Conveyors (photo) is suitable for the gentle transfer of friable food and non-food products, and is offered as a standalone system, or fully integrated with upstream and downstream equipment, including bag-dump stations, bulk-bag dischargers, bulk-bag fillers, container dumpers and more. The conveyor moves material using high-strength polymer discs — affixed to a stainless-steel or galvanized cable — that slides within a smooth stainless-steel tubing. The system can have single or multiple inlets and outlets, and can convey over short distances or hundreds of meters. — *Flexicon Corp., Bethlehem, Pa.*
www.flexicon.com

Detect and reject metals from pills with this machine

The standalone Insight PH metal detector (photo) combines core technologies with additional features to deliver benefits to manufacturers of tablets and capsules. The system is highly resistant to vibration, and its integrated digital search head and Optix detector-management software guarantee detection and rejection of minute metal fragments, while maintaining high productivity. The detector is sensitive to all metals, and can inspect up to 30,000 tablets or capsules per minute. — *Lock Inspection Systems Ltd., Oldham, U.K.*
www.lockinspection.com

This automatic tube filler has a small footprint

The Unipac U 2060 automatic tube filler (photo, p. 56) has an enclosed design that meets ergonomic requirements. With a compact structure (footprint less than 1.5 m^2), the unit is easy to access. Equipped with eight stations, the system is suitable

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

Romaco Group

Intelligrated

for filling semi-solids, such as ointments, creams, gels, pastes and other products in the pharmaceutical and cosmetics industries. The products are filled into aluminum, laminate or polyethylene tubes, which are closed either mechanically (by means of a series of folds) or in a heat-sealing or hot-air process. The machine has a maximum output of 60 tubes/min. — *Romaco Group, Karlsruhe, Germany*
www.romaco.com

A robot to add or load or unload pallets automatically

At Pack Expo (Las Vegas, Nev.; September 23–25), this company presented its Avley robotic palletizing and depalletizing machine (photo). The robot's flexibility, combined with advanced software and vision technology, enables handling of variable loads and products and brings the speed and accuracy of automation to previously manual processes, says the company. The manufacturer offers all the components for complete order-fulfillment solutions, enabling users to phase out manual processes. — *Intelligrated, Mason, Ohio*
www.intelligrated.com

Shrink films for beverage multipacks

Introduced in August, the Bemis Titan brand shrink films and labels are designed to enhance beverage packaging quality, efficiency and brand appeal using advanced polyethylene shrink technology. The film creates vibrant, sustainable shrink multipacks that replace corrugated, paperboard or plastic rings. Multipacks made with these shrink films reduce material weight by 50% and decrease packaging costs by up to 30% compared to paperboard, says the company. — *Bemis Performance Packaging, Oshkosh, Wisc.*
www.bemisperformancepackaging.com

Instant product authentication with a new barcode

Unlike traditional 2D barcodes, which are limited in data capacity and require an internet connection or time consuming database look-ups, the HD Barcode has none of these shortcomings, making it suitable for absolute product authentication. A single code can hold 175 times more data than a traditional 2D barcode, and may contain text, images, HTML and other file types. HD Barcode uses a proprietary reading application that allows an authorized user to scan and read these comprehensive product details in any location. Manufacturers can track and trace information, product specifications, e-pedigree data, plant location, manufacturing date, distribution regions, package carton or label identifiers, user data, and more. — *Complete Inspection Systems, Inc., Indialantic, Fla.*
www.completeinspectionsystems.net

Rigid packaging manufactured from only polyethylene

This company continues to expand its sustainable packaging portfolio with the recent launch of a 100% PE Standup Pouch (SUP). The SUP's

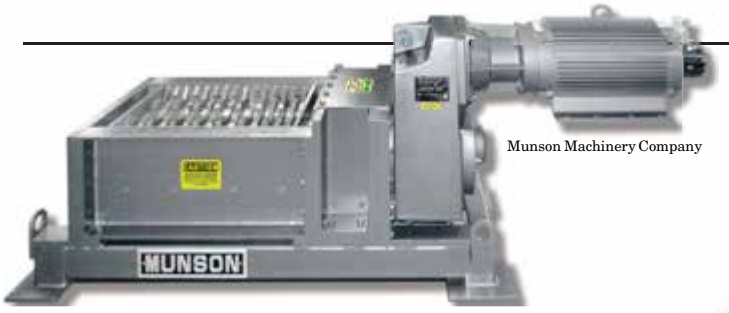

NJMPackaging

structure is made with only one raw material, PE, enabling easier recycling with 83% less plastic used when compared to traditional rigid plastic packages. Also, the monomaterial composition and improved trimmings contribute to lighter weight, which leads to additional cost savings and storage and transportation benefits. The SUPs can be used for cleaning products, beverages, cosmetics, dry and frozen foods and products in the building and construction sector. — *The Dow Chemical Company, Midland, Mich.*
www.dow.com/packaging

A modular tablet counter that delivers fast and accurate filling
The Cremer CFS-622 Tablet Counter (photo) is a servo-driven counting and filling system that features a modular design, accommodating up to four counting modules to fill up to 170 bottles per minute. It handles almost any size tablet, capsule or softgel and fills almost any bottle while achieving 100% counting accuracy, says the manufacturer. The unit's servo-driven feed screw and dipping filling nozzles provide fast and accurate transportation and filling of almost any size bottle. Servo-driven vibratory plates, product separator flaps and discharge flaps provide fast and consistent product flow while minimizing maintenance, adds the company. The system meets 21 CFR Part 11 guidelines. — *NJM-Packaging, Lebanon, N.H.*
www.njmpackaging.com

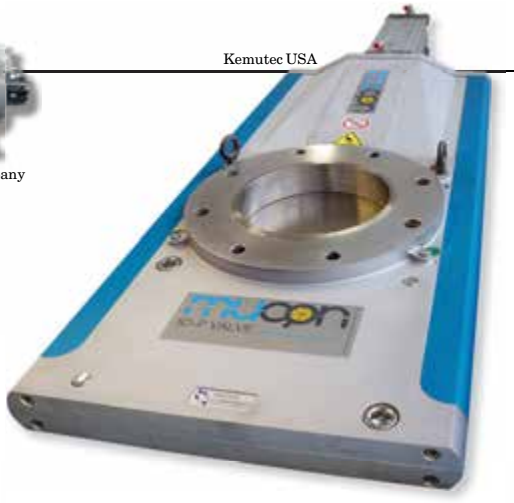
Print compliant labels faster and with better quality
ColorWorks Label Printer technology was introduced to help manufacturers that produce a large number of SKUs (stock-keeping units) manage the chaos associated with different label varieties and to meet new regulatory labeling standards. Launched last month at Pack Expo, ColorWorks offers improved image quality and production speeds. The company says this new technology can help reduce total labeling costs by up to 50% for a wide range of packaging and manufacturing applications. The company also launched its ColorWorks C831 Wide Label Printer to help manufacturers and transporters comply with Globally Harmonized System (GHS) labeling standards. — *Epsom America, Inc., Long Beach, Calif.*
www.pos.epsom.com ■

Gerald Ondrey



Munson Machinery Company

Kemutec USA



OCTOBER New Products

Aalborg Instruments and Controls

Invensys

These slide gate valves prevent leakage with dust-tight seals

This company's range of pneumatic and manually actuated double-flanged inline slide gate valves (photo) have complete shut-off that is applicable for use with powders, granules and pellets. A durable, self-compensating polymer seal ensures that the blade is completely dust-tight, thus preventing material leakage into the environment. Completely unobstructed full-bore openings give these valves smooth, non-jamming operation. Available in diameters from 4 to 12 in., these valves feature stainless-steel construction and a moving orifice side plate. — *Kemutec USA, Bristol, Pa.*
www.kemutecusa.com

Gain access to plant data on mobile devices with this software

New Wonderware InTouch Access Anywhere software (photo) enables users to securely access plant-floor data from mobile devices. The software and its applications are compatible with Android-operated devices, as well as iPads and iPhones. For laptops and personal computers, it also supports Microsoft, Macintosh and Linux-based systems. Giving users the capability to access realtime visualizations of plant information, this software can help plants in lowering costs and improving efficiencies. — *Invensys plc, London*
www.invensys.com

This mini peristaltic pump can handle a wide range of flowrates

The new Model TPT low-flow mini peristaltic pump (photo) provides a small-footprint flow solution for many applications, including pH control, fermentation processes, nutrient dosing and environmental sampling functions. Capable of flows ranging from 1–30 mL/min, users can select from four different speed drives. Pump construction consists of a rigid metal housing, aluminum square tube and top and bottom plates. A glass-filled polytetrafluoroethylene (PTFE) roller head containing four rollers ensures quiet operation. A control switch allows for reversible, clockwise or counterclockwise flow. The pumps feature a brush-style, continuous-duty, 24-V d.c. gear motor with an internal permanent magnet. Also available is an optional counter that indicates the number of revolutions. — *Aalborg Instruments and Controls, Inc., Orangeburg, N.Y.*
www.aalborg.com

Reduce scrap size with this self-cleaning shredder

The Titan 20 shredder, shown in stainless steel (photo), reduces the volume of scrap plastics, resins, fibrous products, fiberglass, wood products, paper and cardboard, gypsum wallboard, aluminum, glass, and other industrial, medical and manufacturing waste products by up to 80%. The self-cleaning shredder features dual rotors with extended cutter teeth that chop and shred large volumes of large solids with minimal power consumption. Constructed of hardened heat-treated material, the cutter blades are mounted along two

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

Circle 17 on p. 60 or go to adlinks.che.com/45777-17

New Products

parallel shafts that are hexagonal in cross-section. Options include auto-reversing controls, ram feeders, extended support legs, specialized hoppers, and gravity or pneumatic transitions. — *Munson Machinery Company Inc., Utica, N.Y.*
www.munsonmachinery.com

Use this pump module to detect toxic gases in remote areas

The SM100 Sampling Pump Module (photo) draws combustible or toxic gases for detection and monitoring in areas that are too remote, inaccessible or too cold, hot or wet for direct sensor monitoring. The SMP100's stainless-steel design makes it suitable for gas-detection service in harsh conditions and at humidity up to 95%. The pump module's applications include gas detection in wet wells, sewage dryers, print drying ovens, storage tanks and ducts carrying toxic or combustible gas. Featuring a low-flow indicator and trouble relay with local signal indication, the SM100 is capable of flows from 0.05–1.0 L/min, with an operating temperature range of –4 to 131°F. The SMP100 is available in two configurations, an aspirated model that is used with a compressed air source, and a d.c. pump module. — *General Monitors, Lake Forest, Calif.*
www.generalmonitors.com

General Monitors


Southworth Products

Move skids or pallets with this versatile ergonomic lift table

The low-profile LiftMat lift table (photo) allows users to access loads from all four sides with no bending and minimal reach-over, reducing worker fatigue, back strain and injuries. Descending to just 3.25 in. above the ground, LiftMat can accommodate any skid or pallet, including closed-bottom designs. As boxes are added or removed, the platform is smoothly raised or lowered to the most comfortable height with a powered foot-switch, a hand-held push-button remote, or a wall-mounted switch. A full-perimeter, auto-stop safety toe-guard instantly stops descent when it comes in contact with any obstruction. The LiftMat's full raised height is 31.5 in. Available with 15 platform sizes, the LiftMat has a total load capacity of 2,200 lb. — *Southworth Products Corp., Portland, Maine*
www.southworthproducts.com

T & D

Wirelessly monitor temperature and humidity with this logger

The TR-702 temperature and humidity data logger (photo) comes in two versions: one with integrated Ethernet and the other with wireless capabilities. The loggers keep users abreast of current readings and recorded data via automatic file transfer or E-mail. The TR-702 has an internal Web server for directly viewing current readings and is fully compatible with the company's cloud-based Web storage services. With a temperature range of 0–55°C and a relative humidity range of 10–95%, the TR-702 features a contact closure for triggering an external device in the event of an alarm condition. — *T & D Corp., Santa Fe, N.M.*
www.tandd.com ■

Mary Page Bailey

weftec® 2013
the water quality event

The 86th Annual Water Environment Federation Technical Exhibition and Conference (Weftec) will be held this October at the McCormick Place South Convention Center in Chicago. The conference runs October 5–9, with the exhibition taking place on October 7–9 and will feature more than 140 technical sessions and 27 workshops. Over 750 exhibitors will be showcased on the tradeshow floor. The following preview highlights a small sampling of these exhibitors' products and services.


Fluid Components International


Watson-Marlow Pumps Group


Moyno


McCrometer


Neptune Chemical Pump

This gas flowmeter achieves a 1,000:1 turndown ratio

The ST100 flowmeter (photo) measures gas mass flowrate, total flow, temperature and pressure, storing up to five unique calibration groups to accommodate broad flow ranges at up to 1,000:1 turndown. The meter continuously displays all process measurements and alarm status, and it has the ability to query for service diagnostics. Information is displayed on the meter's graphical, multivariable, backlit LCD display screen. With a maximum operating temperature of 850°F, the ST100 is designed for a wide range of plant operations, including wastewater applications for aeration systems, digester gas and disinfection gas. Booth 3944 — *Fluid Components International, LLC, San Marcos, Calif.*
www.fluidcomponents.com

This full-profile-insertion flowmeter features hot-tap installation

The FPI Mag full-profile-insertion electromagnetic flowmeter (photo) features an accuracy of up to ±0.5%. The FPI Mag boasts simple hot-tap installation, requiring no service interruption, making it a good fit for retrofits, upgrades and maintenance projects. Hot-tap installation also reduces installation time by eliminating the need to de-water lines or cut pipe. The FPI Mag flowmeter is available for forward-only or bi-directional measurement in line sizes ranging from 4 to 138 in. Booth 1319 — *McCrometer, Inc., Hemet, Calif.*
www.mccrometer.com

A mechanically actuated diaphragm pump designed for water

This company's Series 7000 mechanically actuated diaphragm metering pumps (photo) are designed specifically for water and wastewater applications. The mechanical design of the Series 7000 eliminates the use of contour plates on the liquid side of the diaphragm while the straight-through valve and head design allows for improved flow characteristics. The Series 7000 is self-priming and has a maximum capacity range of up to 300 gal/h (1,135 L/h) at 150 psi. Pump capacity is adjustable by micrometer dial while the pump is running. Booth 2605 — *Neptune Chemical Pump Co., North Wales, Pa.*
www.neptune1.com

A turnkey skid is a single-source peristaltic metering solution

This company's turnkey peristaltic chemical metering systems (photo) combine pumps, gages, columns and other accessories into a robust skid solution. Fully integrated and tested, the skids decrease installation time and costs, allowing users to obtain an entire system from a single source. In addition, each peristaltic skid features provisions for pressure relief, pump isolation and fluid calibration as standard without the need for degassing valves, strainers, back pressure valves, pulsation dampeners or other ancillary items typically associated with diaphragm pump systems. Booth 2416 — *Watson-Marlow Pumps Group, Wilmington, Mass.*
www.wmpg.com

A convenient alternative to gravity-based sewers

The new InviziQ pressure sewage system (photo) is an alternative to con-

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

Show Preview

Vanton Pump and Equipment

Endress + Hauser

Georg Fischer Piping Systems

ventional gravity sewage options, giving users the flexibility to build and operate in almost any location. Rather than relying on gravity and a network of lift stations to transfer sewage, InviziQ pressure sewage systems utilize grinding and pumping technology for controlled movement of sewage to treatment facilities, even in areas with complex terrain topography or environmental sensitivity. The system's dry well design delivers clean access to the unit's motor and other working parts. Other features include stainless-steel pump cartridge, 150-gal emergency storage capacity and diagnostic software. Booth 436 — *Moyno, Inc., Springfield, Ohio*
www.moyno.com

Use these pumps across a very broad pH range

This company's line of thermoplastic pumps (photo) are engineered to handle chemicals and waste streams over a very broad pH range. Designed for use in industrial environments that handle water and wastewater, these pumps are also appropriate for applications involving the handling, dosing, collecting and transferring of corrosive or abrasive fluids. The pumps are engineered to individual requirements and are available in a variety of configurations, including: ANSI, mag-drive, close-coupled, self-priming, vertical to 20 ft and run-dry cantilevered. Booth 2459 — *Vanton Pump and Equipment Corp., Hillside, N.J.*
www.vanton.com

Remove ammonia from wastewater with this treatment system

Demon water treatment systems (photo) remove nitrogen from municipal and industrial wastewater streams that have high ammonia concentrations. The Demon system features ammonia-oxidizing bacteria (AOB), which convert half the ammonia to nitrite. A second anaerobic biological process uses anaerobic ammonium-oxidation bacteria to convert the combination of nitrite and remaining ammonia directly into nitrogen gas. This system requires less energy, eliminates the need for additional chemicals, and produces significantly less sludge, when compared to traditional nitrogen removal processes. The anaerobic process consumes carbon dioxide, giving this system a very low carbon footprint. Booth 736 — *World Water Works, Inc., Oklahoma City, Okla.*
www.worldwaterworks.com

Access data remotely with this Web-integrated transmitter

Liquiline CM44x multichannel transmitters (photo) monitor and control processes in many industries, such as water and wastewater, chemicals, oil-and-gas and power. These transmitters can accept inputs from up to eight digital sensors, including nitrate, spectral absorption coefficient (SAC), pH, conductivity, dissolved oxygen, turbidity, free-chlorine and ion-selective electrode sensors. Optional current inputs are available for processing signals from other process devices, such as flow, level or pressure sensors. Internet connection is available through the CM44x's Ethernet port, allowing users to perform remote configuration or access device parameters via an integrated Web server. Featuring a backlit display, the transmitter alerts users to errors, displays load curves and also allows for configurable viewing of the built-in data logger. Booth 3246 — *Endress + Hauser, Inc., Greenwood, Ind.*
www.us.endress.com

This transmitter offers batch controller capabilities

The new Signet 9900 transmitter (photo) supports multiple parameters that include flow, pH, conductivity, resistivity, salinity, temperature, pressure and level. With optional batch and relay modules, this transmitter can also be converted to a batch controller system. The 9900 features a 3.90-in. by 3.90-in. auto-sensing backlit display with large, illuminated characters, allowing for visibility even at long distances. The display shows separate lines for units, main and secondary measurements as well as a dial-type digital bar graph. Other capabilities include relay and warning LEDs and an intuitive menu for customized programming. Booth 213 — *Georg Fischer Piping Systems, Schaffhausen, Switzerland*
www.gfpiping.com ■

Mary Page Bailey

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CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Maximizing Fan Efficiency

Optimizing fan performance can help plants reach overall process efficiency goals. The cost of powering fans and ventilators in the chemical process industries (CPI) is significant. For example, ventilation and air-pollution control systems can account for over a quarter of energy a facility's consumption. Fan performance is typically estimated by using a graph that shows the different pressures generated by the fan and the corresponding power required. Understanding this relationship helps in designing and operating a fan system.

Fans behave according to a predictable set of laws involving the speed (revolutions per minute), pressure and power. Airflow is proportional to fan speed, while static air pressure is proportional to the square of the speed. Power required to operate the fan is proportional to the cube of the speed. For example, decreasing fan speed by 10% results in a 10% drop in air delivery, but a 19% drop in static pressure and a 27% drop in power requirements.

Fan efficiency — the ratio between the power transferred to the air stream and the power delivered by the motor to the fan — provides a useful quantity to assess improvements in fan performance. The following offers equations for calculating fan efficiency and tips for maximizing it.

TABLE 1. FAN EFFICIENCY PEAKS

Type of fan	Peak efficiency range
Centrifugal fans	
Airfoil, backward curved and inclined	79–83
Modified radial	72–79
Radial	69–75
Pressure blower	58–68
Forward curved	60–65
Axial fans	
Vane axial	78–85
Tube axial	67–72
Propeller	45–50

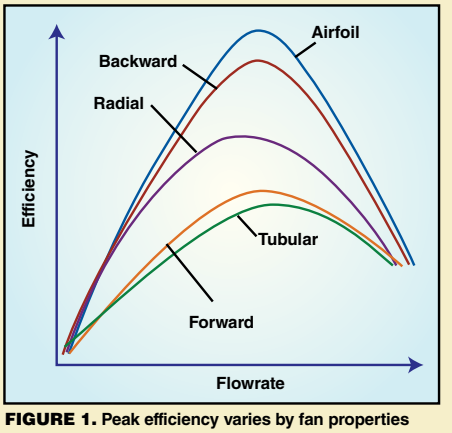

FIGURE 1. Peak efficiency varies by fan properties

Calculating fan efficiency

Although fan efficiency depends on the type of fan and the geometry and shape of the impeller, generally speaking, as gas or air flowrate increases, the efficiency of the fan increases to a certain maximum height ("peak efficiency"), and then decreases with further increasing flowrate (Figure 1). Peak efficiency ranges for various types of centrifugal and axial fans differ (Table 1). Operators should note that peak points of fan efficiency may not coincide with the most stable point of operation.

Five steps are generally required to assess the efficiency of a fan.

Step 1. Calculate gas density.

$$\text{Gas density} = (273 \times 1.293) / 273 + t\,^{\circ}\text{C} \quad (1)$$

Where t represents temperature of air or gas at site conditions

Step 2. Measure the air velocity and calculate average air velocity.

The air velocity can be measured with a pitot tube and a manometer, a flow sensor device or an anemometer.

The average air velocity can be calculated after taking a number of velocity-pressure readings across the cross-section of the duct using the following equation:

$$v = \frac{C_p \times \sqrt{2 \times 9.81 \times \Delta P \times \gamma}}{\gamma} \quad (2)$$

Where C_p = Pitot tube constant 0.85 or given by manufacturer

ΔP = average differential pressure, as measured by a pitot tube. Measurements are taken at a number of points across the cross-section of the duct

γ = density of gas at test conditions

Step 3. Calculate volumetric flow (Q, in m^3/sec). Take the duct diameter (or the circumference from which the diameter can be estimated).

$$Q = \text{Velocity } V\,(\text{m/s}) \times \text{Area } (\text{m}^2) \quad (3)$$

Step 4. Measure the power of the drive motor. The power of the drive motor in kilowatts (kW) can be measured by a load analyzer.

Step 5. Calculate the fan's mechanical efficiency and static efficiency. The two use the same equation, except that for static efficiency, the outlet velocity pressure is not added to the fan static pressure.

$$\eta_{mechanical} = \frac{Volume, m^3/time, s \times \Delta P(total\ pressure), mmWC}{102 \times power\ input\ to\ fan\ shaft\ in\ kW} \times 100 \quad (4)$$

Improving fan efficiency

Improving the performance of fans through a "systems approach" requires understanding the interactions between the fan and the equipment that supports fan operation, as well as the components that are served by fans. Here is a list of items that can help improve fan and fan-system operation:

- Use smooth, well-rounded air inlet cones for fan air intake
- Avoid poor flow distribution at the fan inlet
- Minimize fan inlet and outlet obstructions
- Clean screens, filters and fan blades regularly
- Minimize fan speed
- Use low slip or flat belts for power transmission
- Check belt tension regularly
- Eliminate variable-pitch pulleys
- Use variable speed drives for large variable fan loads
- Use energy-efficient motors for continuous or near continuous operation
- Eliminate leaks in ducts
- Minimize bends in ducts
- Turn fans and blowers off when they are not needed
- Reduce the fan speed by pulley diameter modifications incase of oversized motors
- Adopt inlet guide vanes in place of discharge damper control
- Change metallic or glass-reinforced plastic (GRP) impeller by more energy efficient hollow fiber-reinforced plastic (FRP) impeller with aerofoil design
- Try to operate the fan near its best efficiency point (BEP)
- Reduce transmission losses by using energy-efficient flat belts or cogged raw-edged V-belts instead of conventional V-belt systems
- Minimizing system resistance and pressure drops by improving the duct system
- Ensure proper alignment between drive and driven system
- Ensure proper power supply quality to the motor drive
- Regularly check for vibration trend to predict any incipient failures like bearing damage, misalignments, imbalance, foundation looseness and so on
- Maintain fans regularly, including periodic inspection of system components, bearing lubrication and replacement, belt tightening, motor repair and fan cleaning
- Consider the following items for fan selection: noise, purchase cost, operating cost, operating life, rotational speed, air-stream characteristics, temperature range, space constraints and system layout

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Technology Profile

Ethanol from Sugarcane

By Intratec Solutions

Ethanol is a widely used commodity chemical with several applications, including use as a solvent and as a gasoline blendstock in the fuel market. Globally, the major portion of ethanol production is based on the fermentation of sugars from crop feedstocks, such as sugarcane, corn, cellulosic material and others. World fuel ethanol production is about 85 billion liters annually, with 60% resulting from corn ethanol production in the U.S., and another 25% from sugarcane ethanol production in Brazil. In view of current environmental issues, including greenhouse gas emissions, fermentation-based ethanol is considered an alternative to fossil fuels since it originates from renewable resources.

The process

Ethanol from sugarcane is traditionally produced by yeast fermentation of sugarcane molasses. Commonly, raw sugar is obtained as a co-product, through crystallization of sugarcane raw juice. The major process steps in sugarcane ethanol production (Figure 1) are as follows:

Milling. Sugarcane is delivered from the field to the factory, where it is weighed, cut and shredded before being conducted to the mills, where the raw cane juice is extracted. Sugarcane bagasse is obtained as a residue, and it is burned to generate steam and electricity to supply process demands.

Juice treatment. The raw cane juice is clarified by treatment with phosphate and lime leading to mud formation, which is separated in a clarifier. The clarified juice is then concentrated under vacuum in a multiple-effect evaporator, forming a sugar syrup.

Sugar crystallization. Sugar crystallization is accomplished in two vacuum calandrias, where water is evaporated from the syrup and crystallization is induced by the addition of a seeding solution. This process forms a massecuite, a mixture of liquor and sugar crystals. Next, crystallization is completed by cooling in a crystallizer. The raw sugar is centrifuged, dried and sent to storage. In a third calandria-crystallizer set, a massecuite is formed that will become the seeding solution to be used at crystallization, and also the molasses for subsequent fermentation.

Fermentation. The sugars contained in the molasses are fermented to ethanol by yeast. Gases released from the fermentation are washed with recycle water in a gas-washing column. The final broth is centrifuged, and the yeast cells are treated with sulfuric acid and recycled to the first fermenter. Meanwhile, the ethanol-containing wine is sent to a distillation apparatus.

Distillation. The ethanol solution is heated and fed to the concentration column. The overhead of this column is sent to the gas-washing column and the vapor-side product stream, containing about 50% ethanol, is fed to a rectifying column that generates a 90% ethanol vapor stream and recycle water, which goes to the gas-washing column. The ethanol product stream undergoes dehydration in a molecular sieve unit, leading to a product that is 99.5% pure ethanol.

Economic performance

An economic evaluation of the process was conducted based on data from the fourth quarter of 2012 (Figure 2). The following assumptions were taken into consideration:

- A 6 million-ton/yr sugarcane processing unit producing 270 million L of anhydrous ethanol and 420,000 ton of raw sugar per year built in Brazil (the process equipment is represented in the simplified flowsheet below in Figure 1)
- The unit operates 210 d/yr
- Storage capacity equal to 30 days of operation for sugar and ethanol
- Sugarcane cultivation and harvesting costs were not considered
- The electricity surplus generated in the plant is sold to the electric grid

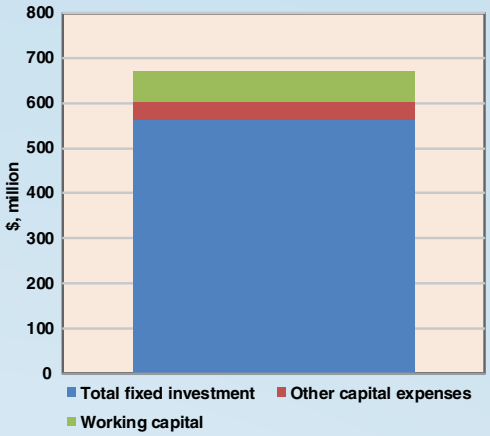

FIGURE 2. Capital expentitures for a sugarcane ethanol plant erected in Brazil

The estimated capital investment (including total fixed investment, working capital and other capital expenses) is about $670 million.

The process reported here allows sugarcane ethanol manufacturers to balance ethanol and sugar production yields according to demand, rendering the activity flexible to market fluctuations.

Brazil is the main sugarcane ethanol producer and experienced, in the first semester of 2013, a 7% increase in fuel ethanol consumption when compared to the same period of 2012. ■

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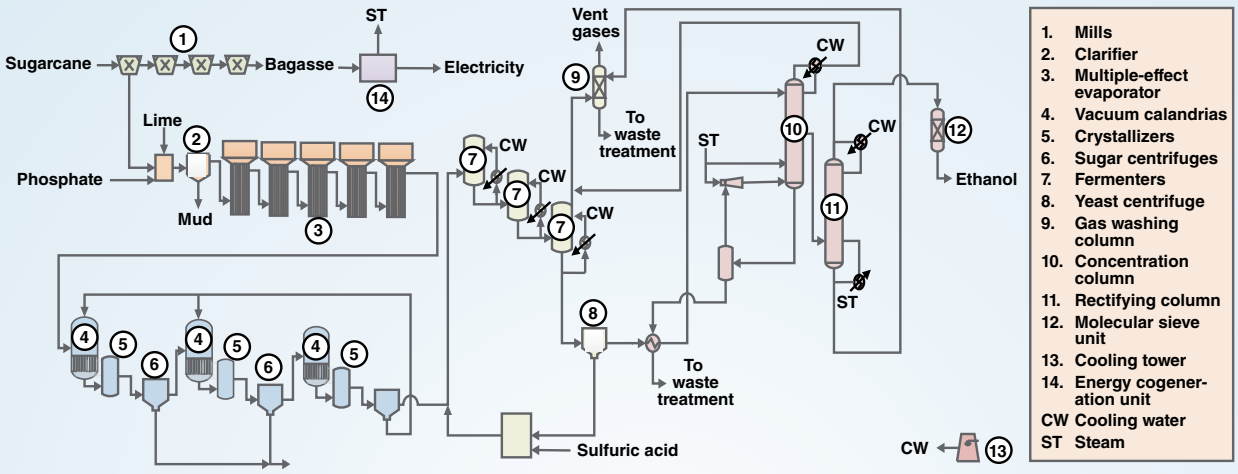

FIGURE 1. Traditional ethanol production process from sugarcane

BIOLOGICAL WASTEWATER TREATMENT: Selecting the Process

FIGURE 1. Assorted media is used to carry biomass in an MBBR system

Basic steps for developing an industrial-water-treatment process are given, using an example of a difficult-to-biodegrade wastewater stream

Li An
Veolia Water Solutions & Technologies

Chemical, pharmaceutical and related industries produce large amounts of wastewater in their production and cleaning processes. The wastewater characteristics are often diverse, and may include minimally biodegradable or toxic substances, or both. To protect the environment, these wastewaters typically must be treated to minimize pollutant concentrations before discharging to the environment, or to municipal wastewater-treatment plants for further treatment. Compared to chemical and physical treatment methods, biological treatment processes are very economical and efficient options when the wastewaters contain biodegradable pollutants.

Biological wastewater-treatment processes are widely adapted to remove soluble, colloidal and suspended organic substances. Biological treatment is also used for nitrogen and phosphorus removal. The two categories of biological treatment are suspended-growth and attached-growth processes. In the suspended-growth category, the most widely used process is activated sludge. An attached-growth process that can provide the same treatment capacity as activated sludge in a smaller footprint (60% less) is the moving bed biofilm reactor (MBBR). The first MBBR was installed in Steinsholt, Norway in 1989. Today, as regulatory restrictions continue to become more stringent, MBBR technology is becoming increasingly popular due to its application flexibility.

An MBBR system uses inert, plastic media in various configurations (Figure 1) to provide high surface area to carry the biomass that treats the wastewater. Aeration grids installed at the bottom of the tank provide the oxygen needed for the bacteria to thrive and to keep the carriers in suspension within the tank (Figure 2). The movement of the carriers in the tank maintains a thin biofilm on the media (Figure 3).

Using a specific example from pharmaceutical company AstraZeneca, this article explains how a biological wastewater-treatment process was developed for a challenging situation where the wastewater contained toxic constituents.

Basic process comparison

Activated sludge is a conventional biological wastewater-treatment process. It has been used extensively in its original form, as well as with many modifications. There are three basic components in the activated sludge process: (1) a biological reactor in which the microorganisms responsible for treatment are kept in suspension and aerated; (2) a clarifier for liquid-solids separation; and (3) a recycle system for returning solids removed from the liquid-solids separation unit back to the reactor. A typical activated sludge process is shown in Figure 4.

Activated sludge is a widely used biological treatment process. It produces a good-quality effluent, but is more sensitive than an MBBR to shock loads and toxic matter. The system is associated with biomass instability issues, such as sludge bulking. Skilled operators are required to check that the returned sludge remains active, and to adjust the operating conditions to react to the changes immediately.

In an MBBR system, biofilm is attached and grown onto the surface of plastic media. The media and biofilm are retained in the reactor by sieves. Only a small portion of sloughed-off biofilm exits the MBBR tank together with the liquid. As a result, there is no need for sludge recycling in an MBBR system. Figure 5 shows the configuration of a basic MBBR system.

Compared to activated sludge systems, MBBR has more sludge in the reactor and a higher sludge age. The higher sludge age makes it possible for the biomass in the MBBR to adapt to complex molecules and ultimately to degrade them. MBBR is also more tolerant to shocks of both hydraulic and organic loads, making it a better choice for wastewater with varying flow and characteristics. With the larger amount of sludge in the system, the MBBR can be designed at a higher loading rate, thus reducing the footprint as compared to activated sludge. Multistage MBBR processes can use different biomass in the subsequent stages to target specific difficult-to-

FIGURE 2. Aeration grids in the bottom of an MBBR reactor supply the oxygen needed for biomass growth

degrade pollutants in each stage. Because a sludge recycle system is not needed, the operation of an MBBR is much simpler and robust than an activated-sludge system.

Choosing the best approach

Every biological process has its advantages and disadvantages. In practice, the selection of the most appropriate process needs to consider both technical and economical factors. The decision is made based on a balance between these two aspects. Technically, the appropriate process is determined according to the wastewater characteristics, discharge requirements, available plant space and allocated budget.

The diversity of process waters within the chemical and pharmaceutical industries is enormous. Typical characteristics for wastewaters from the chemical and pharmaceutical industries include:

- High organic content, of which some components (typically solvents such as alcohols or glycols) are easily degradable
- Variations in flow and influent wastewater characteristics caused by campaign production and varying compositions
- The presence of toxic and persistent substances

Because of the diversity of wastewaters generated by these industries, each application usually calls for a tailor-made treatment solution. A bench-scale or pilot-scale test is often necessary to verify treatment efficacy and establish the optimal operating parameters. If toxic or persistent substances are present, the biological treatment process may require lower loading rates or multistage steps to achieve the desired treatment results.

Besides the wastewater characteristics, effluent discharge limits for the treated waters also vary due to local regulations, discharge location and the sensitivity of the receiving environment. Sometimes the main treatment requirement is biochemical oxygen demand (BOD), but removal of other specific compounds, nutrients and toxic substances also may be mandated. The ability of the alternate treatment processes to meet the specified discharge requirements is the first criterion to be met before other considerations, such as cost and ease of operation, are evaluated.

FIGURE 3. Biological growth on the carrier forms a thin biofilm on the media in an MBBR system

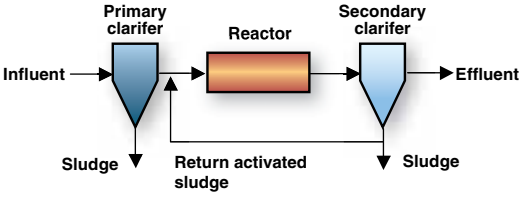

FIGURE 4. Activated sludge is a conventional biological treatment process

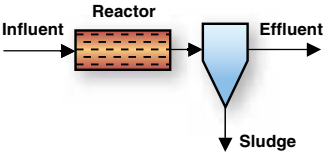

FIGURE 5. An MBBR process requires no sludge recycling

Limited plant space is a common situation that often becomes a factor in choosing a biological treatment system. In such cases, engineers are forced to consider only those processes with smaller footprints, even though they may not be optimal for the situation and may require much higher capital and operational costs.

In addition to technical aspects, economic concerns must be considered. The capital and operating costs of any option impact the process selection and may become the deciding factor. If a selected process costs more than what a plant can afford, lower-cost alternatives may have to be evaluated, even though they are not technically optimal. A comparison of capital cost outlay versus lifetime operating costs may also tip the scale in some decisions, particularly in difficult economic times. Intangible costs like system reliability, ease of operation and technical support over the lifetime of the installation should be taken into account. However, this article focuses primarily on technical considerations.

A case study

This case study details the wastewater treatment needs of pharmaceutical company AstraZeneca. AstraZeneca has separate primary and secondary manufacturing sites that are four miles away from each other in the town of Södertälje, Sweden. The flow-

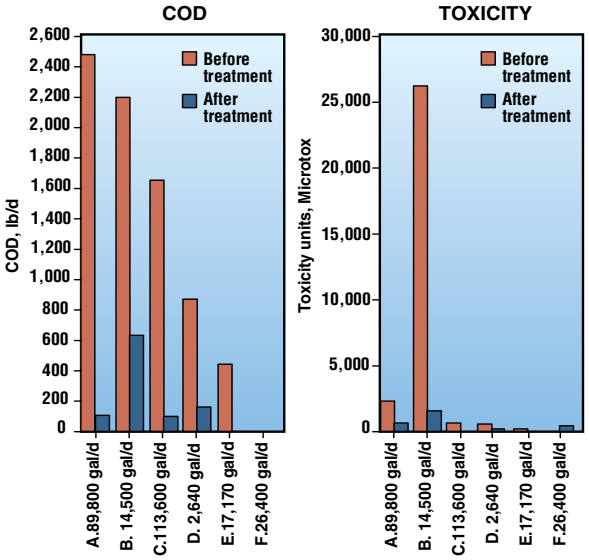

FIGURE 6. These charts show COD and toxicity before and after biological treatment of primary plant wastewater [*1*]

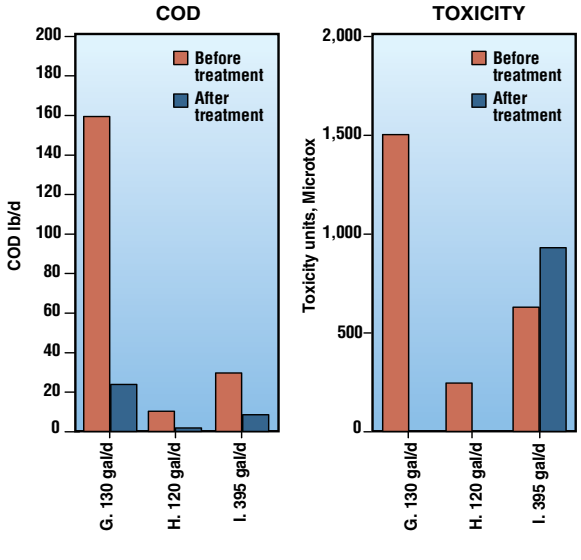

FIGURE 7. These charts show COD and toxicity before and after biological treatment of secondary plant wastewater [*1*]

rate of wastewater from the primary plant was 260,000 gallons per day (gal/d) with chemical oxygen demand (COD) of 3,000–4,000 milligrams/liter (mg/L). The flowrate of wastewater from the secondary plant was 26,000 gal/d with COD of 80–1,600 mg/L. These two sites are connected by a sewage line. The primary plant used activated sludge to treat its wastewater; the secondary plant used activated carbon for the removal of toxicity.

A Swedish Environmental Protection Agency (EPA) investigation showed that these wastewaters were very toxic and contained hard-to-degrade organics and phosphorus, and stricter limits were about to be issued. To ensure compliance with the anticipated regulations, AstraZeneca decided to build a new wastewater treatment plant to meet the requirements for discharge of the treated wastewater to Lake Mälaren. This lake neighbors several cities, including Stockholm.

AstraZeneca sought alternative methods to obtain a solution for the new treatment plant. To be able to discharge the wastewater into Lake Mälaren, the treatment plant effluent had to be free of toxic chemicals and, at the same time, at least 95% of the organic content had to be removed. The wastewater was evaluated and an optimal biological treatment approach was developed to meet the discharge requirements. Below is the step-by-step process used to evaluate the alternatives and develop the best treatment option.

Step 1: Obtain wastewater characteristics and site information. Flowrates, wastewater characteristics, discharge limits and local environmental conditions were among the data obtained from the sites. The space at the primary plant was limited, but there was space for the new wastewater-treatment facility at the secondary plant.

Step 2: Evaluate and summarize the information. According to the information collected, the toxicity of the wastewater in question was a major problem. Toxic substances typically inhibit biological treatment. In some cases, the bacteria can become acclimated to the toxic wastewater, and sometimes toxic wastewater can be pre-treated to become biodegradable. If no economical pre-treatment can make the toxic wastewater biodegradable, a non-biological treatment must be considered.

Step 3: Examine the wastewater's biodegradablility. If the wastewater has common characteristics and information can be drawn from project experience, laboratory testing is not necessary. However, laboratory testing is recommended for complex industrial wastewaters such as these. An initial evaluation was conducted in the laboratory to determine whether the wastewater was biodegradable and whether the toxicity of the wastewater would be reduced after the biological treatment. Various wastewater streams (labelled A through I) were collected from both the primary and secondary plants. A continuous laboratory-scale activated-sludge process was used for this work. The temperature for the study was 20°C and the pH was 7. Influent and effluent COD and toxicity were measured. The contribution of toxicity from each stream was calculated as toxicity units, as measured by a Microtox test system, which uses luminescent bacteria to determine the toxicity of a sample. When exposed to a toxic sample, the amount of light emitted by the bacteria is decreased. The more toxic a sample, the less light will be produced by the bacteria. Here, toxicity is calculated as flowrate in m^3/day × 100/EC 50, 15 min, where EC50, 15 min represents the effective concentration (EC) of a sample that will cause a 50% reduction in light emission after 15 minutes of exposure of a sample to the test bacteria[*1*]. The laboratory study results are shown in Figure 6 (for the primary plant) and Figure 7 (for the secondary plant).

Based on the results shown in Figure

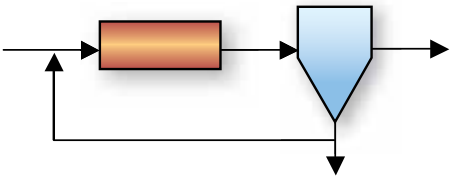

FIGURE 8. Option 1 tested a conventional activated-sludge process including one reactor and one secondary clarifier

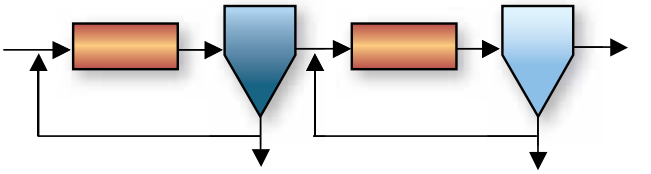

FIGURE 9. Option 2 tested a two-stage activated-sludge process with different sludges

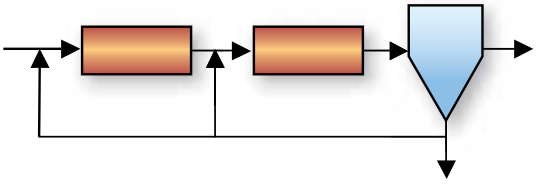

FIGURE 10. Option 3 tested a two-stage activated-sludge process with the same sludge in both tanks

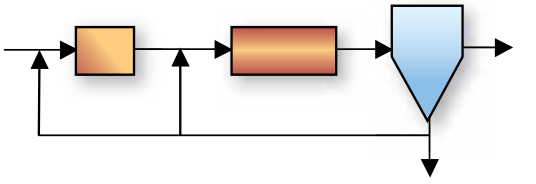

FIGURE 11. Option 4 tested a modified activated-sludge process with an aerobic selector

6, the COD and toxicity are significantly removed by the biological treatment process. From the left chart of Figure 6, we can see Stream B of the primary plant contains some hard-to-treat compounds. From the right chart of Figure 6, we can see that Stream B has high toxicity before biological treatment, but the toxicity is lower after biological treatment. When the biological effluent was further treated by activated carbon, the toxicity was completely removed. The specific components of Stream B that indicated higher toxicity were separated at the source. Activated carbon was also used to polish the effluent by removing the maximum toxicity.

Figure 7 shows the results of COD and toxicity treatment for the secondary plant wastewater. Stream G had both high COD and toxicity, but both COD and toxicity were significantly removed by biological treatment. Stream I had lower COD but relatively high toxicity. To minimize the toxicity of the wastewater, activated carbon was used to pre-treat Stream I.

It could be concluded, based on the results of the initial evaluation, that the wastewater from both plants could be treated with a biological treatment system by employing appropriate pretreatment.

Step 4: Assess potential biological treatment options. When it is known that the wastewater is biodegradable, the next step is to choose the best biological-treatment approach for the specific wastewater. For industrial wastewater with typical characteristics, it is possible to determine the appropriate biological-treatment approach without testing, simply based on expertise. However, biological treatment mechanisms are complex. If the industrial waste stream has challenging characteristics, the best way to select the appropriate biological wastewater-treatment approach is to test the wastewater by laboratory or pilot study.

The wastewater from the primary plant was tested using nine different combinations of continuous activated sludge, and MBBR processes, or both, in the laboratory. These combinations included fungi and bacteria in different reactors in a series. The processes were evaluated based on the removal efficiencies of both COD and toxicity. Sludge volume index (SVI) was adapted to evaluate the settling characteristics of the generated sludge. A microscope was also used to examine the generated sludge. Appropriate media was placed in the MBBR reactors as the carrier for the microorganism growth. The system temperature was maintained at 30°C and pH was maintained at 7. Details of the results from each of the nine test options are below.

A conventional single-stage activated sludge process (Figure 8) was tested as Option 1. It included one activated sludge reactor and one secondary clarifier. This process removed over 90% of the COD at a hydraulic retention time (HRT) larger than 16 hours. The SVI of the sludge was greater than 200, which was not acceptable; therefore, Option 1's single-stage conventional sludge process was eliminated as a potential treatment option for this wastewater.

Option 2 tested a two-stage activated sludge process (Figure 9) with different types of sludge in each tank. This process allowed for different bacteria in each reactor so that the bacteria could work on specific wastewater constituents. The results showed that the sludge in the first reactor did not settle well, and the sludge in the second reactor was not viable when the first stage had high removal rates. Hence, Option 2 was not considered as an approach for the treatment of this wastewater.

Option 3 is a modification of the two-stage process (Figure 10) with two different sludges. Sludge settling and wash-out problems were evident with this approach, so Option 3 was eliminated from consideration.

Option 4 tested a modified activated sludge process (Figure 11) that used a selector with one-hour HRT in front of

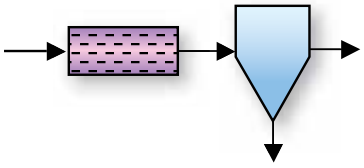

FIGURE 12. Option 5 tested a single-stage bacterial MBBR process

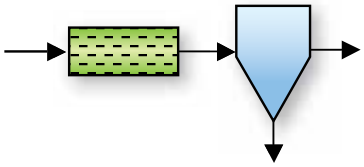

FIGURE 13. Option 6 tested a single-stage fungal MBBR process

front of the conventional activated-sludge process. The selector was run under aerobic conditions. Good removal of soluble COD and total COD were obtained. The SVI was below 80, which indicates the good settling characteristics of the sludge generated by this process. The HRT of the main activated-sludge reactor was 14 hours. This process removed 90–95% COD, but the removal of toxicity was not sufficient. A higher HRT of the main reactor was tested, but this did not remove any additional COD and the sludge deteriorated due to the formation of pinpoint floc. Option 4 showed potential to be considered as a viable solution.

A single-stage, standalone MBBR reactor filled with media (Figure 12) was tested in Option 5. A very high concentration of free bacteria was observed, which was most likely due to the presence of 10–20% readily biodegradable organics in the wastewater. Free bacteria could not be maintained below the HRT of 30 minutes, and the influent was washed out without treatment. Option 5 was not appropriate for the wastewater because of the difficulty in separating the free bacteria from the effluent.

The presence of micro-fungi in the activated sludge treatment plant at the primary plant inspired Option 6, as fungi can affect treatment results. For Option 6, the MBBR reactor was run at a pH of 4 to favor the growth of fungi in the MBBR process (Figure 13). Fungal hyphae quickly formed on the media and yeast cells were observed when the HRT was greater than three hours. However, poor COD removal resulted from the single-stage fungal MBBR process, eliminating Option 6 from further consideration.

Option 7 tested a three-stage fungal MBBR process (Figure 14), where the HRT of each stage was three hours. The pH was controlled at 4. This process removed only 60–70% COD, which was not adequate. Option 7 was abandoned.

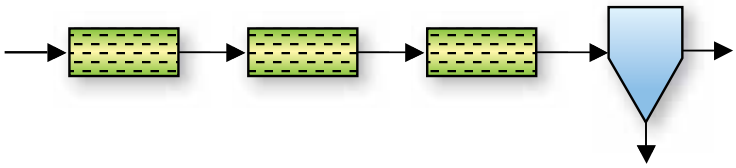

FIGURE 14. Option 7 tested a three-stage fungal MBBR process

Option 8's treatment approach consisted of Option 4 (modified activated sludge) followed by two MBBR reactors (Figure 15). The HRT of this process was 14 hours. The results showed no further COD or toxicity removal compared to the effluent of Option 4, so Option 8 was abandoned.

And lastly, Option 9 was tested in order to remove the remaining COD from the effluent of the three-stage fungal MBBR process in Option 7. Option 9 consists of three fungal MBBR reactors followed by a two-stage bacterial MBBR process (Figure 16). The HRT was three hours for each fungal MBBR reactor. The operational pH was maintained at 4 to benefit the growth of fungi. Two bacterial MBBR reactors were placed after the fungal MBBR stages to remove more biodegradable COD. The pH was maintained at 7 in the bacterial MBBR reactors. This process removed around 90–95% COD, and the removal of toxicity was far more effective than the modified activated sludge process in Option 4. It was easier to separate solid and liquid phases, and the effluent was very

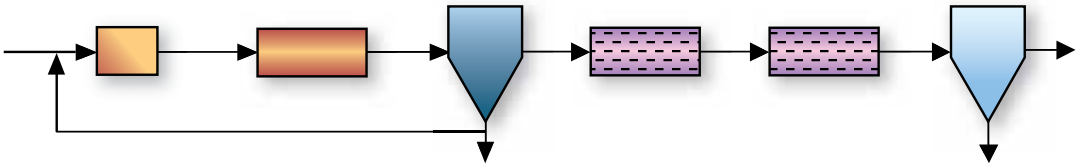

FIGURE 15. Option 8 tested a modified activated sludge process followed by a two-stage bacterial MBBR process

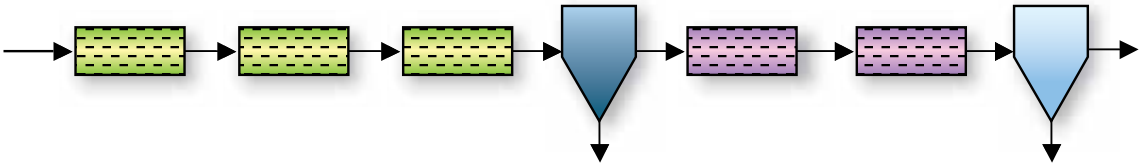

FIGURE 16. Three fungal MBBR reactors followed by a two-stage bacterial MBBR process

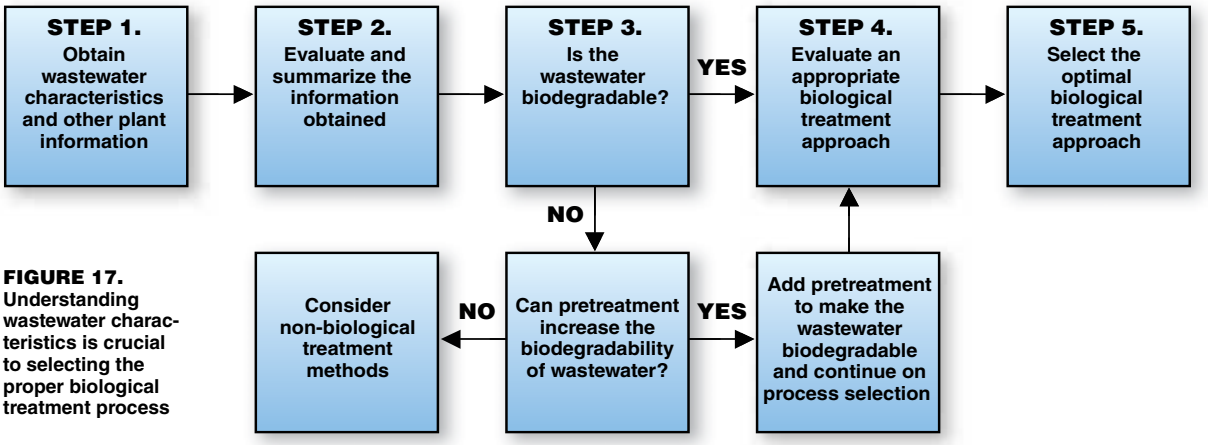

FIGURE 17. Understanding wastewater characteristics is crucial to selecting the proper biological treatment process

clear. This process was deemed an appropriate potential approach for the wastewater.

Further studies showed that when the sludge from the fungal MBBR reactors was removed before the bacterial MBBR treatment, the system exhibited more effective COD and toxicity elimination. Therefore, a clarifier was added in front of the two-stage bacteria MBBR reactors to remove the excess sludge from the previous fungal MBBR reactors.

Step 5: Determine the most appropriate treatment process

Based on the laboratory test results, both Option 4 and Option 9 showed similar COD removal results (90–95%). Option 9 resulted in far better toxicity removal, which could be the result of the longer HRT in the MBBR process. Option 8 showed that adding two MBBR reactors did not improve COD or toxicity removal for the effluent of Option 4. It was thought that the fungal MBBR reactors of Option 9 improved the toxicity removal. According to these results, Option 9 was chosen as the most appropriate biological wastewater-treatment process for this specific wastewater. Pilot tests conducted later confirmed the laboratory test results. In the full-scale installation, activated carbon was also introduced after the biological treatment steps to remove any remaining toxicity in the effluent from Option 9.

A complex, yet simple solution

This case study illustrates the capability of an MBBR system to utilize microbial populations that can target specific constituents in complex wastewater. This capability is a distinct advantage over other biological processes. However, most industrial wastewater is not as complex as the example given here, and the steps to finding the best process for any particular application are as basic as following the steps in Figure 17.

That said, the methods of ensuring that a full-scale MBBR system is designed to operate optimally are properly evaluating the wastewater biodegradability and correctly developing the design parameters of the system, such as the appropriate process, loading rates and air supply. The simplicity of the operation of an optimized system leads observers to believe that filling an aerated tank with plastic media would suffice, but as the AstraZeneca example demonstrates, expertise is gained only by experience.

Concluding remarks

As noted above, cost is almost always a concern when developing or expanding an industrial wastewater-treatment process. In that regard, MBBR has several advantages, as follows:

1. Because of the high surface area of the media, the MBBR process has a very small footprint as compared to an activated sludge system of similar treatment capacity. The smaller footprint can result in lower installation costs and can provide the solution for plants with space constraints.
2. The treatment capacity of MBBR plants can be expanded by simply adding more media to the existing reactors to enable them to treat higher hydraulic and loading rates when manufacturing facilities increase production.
3. The process is flexible in its ability to accept variations of flow and loading.
4. A sludge recycle system is not needed in an MBBR process, thus simplfying operations.
5. Without the need for recycling sludge, the MBBR system has more options for solid/liquid separation. Instead of a conventional clarifier, an MBBR system typically uses small-footprint solid/liquid separation technologies, such as dissolved air flotation, disc-filters or sand-ballasted clarification, reducing the overall system footprint by about 60%.
6. MBBR technology is available in a variety of configurations and materials of construction.
7. As in this case study, specific microbial populations can be developed to address difficult-to-treat wastewater, if required. ■

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The Owner Role in Capital Projects

Avoid delays, cost overruns and more with significant owner involvement

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The Dow Chemical Company

It is well known that the oil-and-gas, chemical and petrochemical industries are capital intensive. They require sophisticated facilities (plants), the installation of which are typically handled via capital projects that, regardless of size, require significant effort from a number of parties for execution. The investing or operating company is typically called the owner and, for a number of reasons discussed in this article, proper involvement of the owner is critical for capital project success. However, some owner representatives and even some owner companies take the approach of letting the engineering, procurement, construction (EPC) companies perform work with minimum involvement from the owner except for regular follow-up meetings. This is typically driven by either lack of resources in the owner's organization or by a misconception that money is saved via this approach. The reality is that such an approach is typically a very expensive proposition.

If this approach is taken during the front-end-loading (FEL) phase under a reimbursable contract, this may lead to one or several of the following problems:

1. Over-sizing in a number of areas as it is technically easier and reduces responsibility
2. Missed opportunities for improvement
3. Items postponed to later phases

If this approach is taken during the EPC phase under a reimbursable contract, the potential issues are similar to those described for the FEL phase. However, if the contract type is lump sum (LS), the potential problems would be more related to quality or additional charges via "change orders".

FEL and EPC phases

In this paper the acronym FEL (for front-end-loading) refers to all work required to prepare a project for execution (or for the EPC phase) including activities such as business case development, scope development and project definition. In some companies or industries, this is called FEED (front-end engineering design) while in other companies or industries FEED only refers to a certain portion of FEL.

In this paper the acronym EPC will be used in two ways: a) to refer to a project phase; in that case the E for engineering will refer to detailed engineering, b) to refer to the companies that provide engineering (all phases of engineering included), procurement and construction services.

Although most of the items discussed in this article apply to both FEL and EPC phases, the emphasis is on the EPC phase, as typically the owner role is better understood for early project phases (FEL). In other words, it is more common to see poor attention from the owner during EPC based on improper assumptions, such as: a) that after FEL scope, standards and owner needs are "totally clear" and therefore that EPC contractor should be able to manage and deliver with minimum interaction from the owner; b) that by having a lump sum or LSTK (LS-turn-key) contract, the responsibility has been transferred to the EPC contractor and there is no need for significant owner involvement.

Classical symptoms and negative results of not enough involvement or attention by the owner team during FEL preparation are as follows:

Improper staffing. In chemical, petrochemical and oil-and-gas projects, the FEL work is typically focused on process engineering. However, some engineering companies tend to understaff the process-engineering function (perhaps because of the limited supply of qualified chemical process engineers in the entire industry) and instead they overstaff other functions (civil, piping, construction, mechanical) for FEL work. This is not only an expensive proposition for the owner, but is also an issue that can create a number of problems with FEL work, as it adds challenges for the process team.

Over-sizing. Equipment might be over-sized because that tends to facilitate the calculations, shorten the schedule and minimize the risk by the designer, and because there might be the "it is not my money" mentality on the engineering side. Accordingly, the owner team needs to continuously check FEL calculations and challenge the design to avoid falling into this over-sizing trap.

Incomplete data sheets. Equipment data sheets might not be properly completed, and entries like TBD (to be decided) or "by vendor" or "by EPC in detailed design" can be overused in the preparation of FEL data sheets. In fact, each data sheet entry that is filled in such a way should be evaluated by the owner for validity, the key question being, "what is not known now that would be known in the EPC phase?"

Passing work on. Some of the FEL work might be passed to the detailed engineering phase, which could create a schedule delay or additional cost to complete FEL work during the detailed engineering phase.

Have strong owner involvement

It is understood that most owner organizations are very lean and focused on running their plants, so it is very difficult for them to properly staff projects, especially considering the tendency in recent years to have multiple simultaneous projects as well as very large projects (also known as mega projects). However, for project success, it is a must to have proper owner representation [*1*].

The following is a list of reasons for having strong owner involvement in all stages of capital projects. Each item will be explained in detail in the following sections.

- Fundamental issues
- Quality
- Schedule and cost considerations
- Performance and staffing issues
- Intervention and risk management
- Contractual issues

Fundamental issues

A fundamental issue is that for an operating company "too much is at stake to have a project handled almost entirely by an engineering staff that does not have to live with the day-to-day operating plant headaches" [*2*]. For the owner, process safety and environmental issues are typically at the top of the list because significant issues in those areas during the life of the plant could have devastating consequences.

On the other hand, it is likely that contractor engineers will not have much operating experience, and although typically quite interested in process safety and the environment, their perspective might be a little different since they would not have to manage the environmental or process safety issues after the plant is turned over to the operating company. A key consideration and something that every project person (regardless of company alignment) should always keep in mind: bad decisions and poor designs typically result in safety or environmental incidents, or other problems over the next 20 to 30 years of plant operation.

In other words, the contractor and owner companies typically have different perspectives from the timing viewpoint: the contractor typically focuses on two to three years (maybe the life of the project if PMC), while the owner needs to also think of the next 20 to 30 years because the owner would need to "live with the assets" (or live with the consequences) through the lifecycle of the plant. By the way, unless issues are very significant or are discovered while the EPC is still involved, the EPC contractor rarely gets enough feedback on how the design really worked.

It is important to recognize the completely different roles and perspectives of the owner and the contractor. There are common goals (for instance, having a successful project) that apply to both parties, but the perspectives are still different. A simple example would be that for one of the parties to maximize profit, the other party might be negatively affected. For that reason in LSTK contracts, it is not always easy to find "win-win" solutions, as in many occasions in terms of cost, quality and schedule, a "win" for the EPC company may mean a "loss" for the owner company, and vice versa. However, this does not mean that owner and EPC companies are "natural enemies". Actually owner and EPC companies are sort of "natural partners"; in spite of the different perspectives and goals there are also common goals and tremendous opportunities for synergies that can be achieved through proper understanding of the other party's role. In fact, proper collaboration between both parties and proper understanding from owner and EPC companies of the other party's role, and respect for those roles, are critical for project success.

For both owner and contractors, cost and schedule are very important for obvious reasons. From the owner viewpoint, long-term considerations regarding safety, quality and reliability are key issues. Those, however, are not necessarily top considerations for all the contractors (especially in LSTK contracts, which tend to be very schedule and cost driven). Problems like safety incidents (at any time in project execution or down the road during plant operation); production losses; poor reliability; product quality issues; excessive maintenance; problems with regulators, authorities and local community are — or will become — owner problems, regardless of contract type. It is impractical to try to delegate those issues to EPC companies.

Note also that safety incidents, low reliability, poor quality, excessive maintenance, damage of company reputation, liabilities and so on would have a much higher economical impact than any claims or liquidated damages that the owner could make to an EPC company.

Some people have described the owner's team role as being the "catalyst", the analogy being that a small amount of involvement facilitates a reaction. As in chemical reactions, if a catalyst is needed and not present, things will either happen very slowly or will go in the "wrong" direction. Of course, as in chemicals reactions, having too much catalyst (that is, too large an owner team that wants to micromanage everything) could also bring another set of problems.

Sometimes there is a misconception that the owner role in EPC is relatively easy; sometimes people erroneously describe the job as "approve the bills" or "watch the contractor". This could be the case in the perfect world that includes a perfect contract, a perfect FEL package and perfect teams in both owner and contractor sides. But in the real world, there are imperfections, and the owner role, if performed properly, is typically extremely demanding. As a result, the owner representatives may become overloaded and forced to move out of their area of expertise and become generalists.

Some people argue that EPC companies tend to perform better when the owner is absent or does not get involved; those arguments are typically based on misconceptions or bad experiences. It is true that EPC companies perform better when allowed to follow their own work processes and procedures (instead of learning new ones). It is also true that owner teams can fall into the trap of trying to micromanage, enforcing owner work processes that do not properly fit or that negatively affect overall productivity or somehow interfere and delay the contractor's work. Needless to say, the owner needs to pay attention and not fall into such traps.

However, it is probably well known

that there are areas in which most EPC companies appreciate owner involvement as they may not have all the necessary expertise or depth knowledge for a given process technology. A typical example is operational issues, because most EPC companies have limited operating experience. The owner can also definitely add value by providing guidance to the EPC companies in areas, such as compliance with and interpretation of the owner standards, owner-specific needs and preferences, and so on.

Another fundamental issue is related to "human nature" as there is a tendency for people to perform better when they know that their work is meaningful (that is, important enough for others to spend time checking it) or when they get feedback on their work. So, as humans, engineers tend to do their best in an environment in which there are professional challenges, timely feedback and intelligent technical discussions. Proper involvement by the owner with the right attitude (including a collaborative approach) is a key to create an environment in which the entire project team can excel and deliver great results.

To summarize this section, due to a number of reasons, the owner needs to manage projects to make sure they are successful; and to properly manage projects the owner team needs to have the capabilities and resources to get properly involved. The owner should not expect good results by using a hands-off approach [*3*].

Quality

One good definition of quality for any product says that "quality is what the customer wants." Such a definition seems to fit well for capital projects (although sometimes "wants" becomes what the customer can afford).

Once the above definition is accepted, then it becomes clear how critical the owner role is in capital projects, as the owner would need to decide and explain "what is wanted" regarding a large number of issues on a day-to-day basis during plant design and project execution. If, for whatever reason, the owner team cannot provide "just-in-time" input, this would typically result in schedule issues, re-work or quality issues (in terms of operability, reliability and durability of the plant). In reimbursable contracts, this would typically lead to over-design.

Ref. 4 provides some interesting examples of "costly mistakes" related to process design and the author explains that "Experienced, multi-talented [petroleum-] refinery engineers would need to reside and work together with younger staff members and engineering contractors in a truly joint-team fashion, and thus successfully meet the project's goals for quality, cost and timelines and ultimately capture a savings of 15–30% on engineering costs by eliminating reworks" [*4*].

A typical root-cause of quality issues is a lack of adequate communication between the disciplines. There is an old saying in the engineering business that "very few design errors result from technical incompetence. Rather, most result from poor project communications …" [*3, 5*]. The owner needs to constantly watch for this sort of issue and intervene as necessary. The owner team can also be a catalyst as far as making sure that the information flows from one discipline to another; however, the owner should be vigilant in avoiding the trap of becoming a key mechanism for communications among disciplines. Significant issues regarding information flow between disciplines on the contractor side need to be quickly and properly addressed by the contractor; trying to get the limited owner resources to mitigate significant deficiencies in such critical aspects would not be sufficient.

The owner team has responsibilities for watching the quality of the design and deliverables, and therefore has a key role to review and provide input to a large number of documents, such as piping and instrumentation diagrams (P&IDs), data sheets, vendor data, 3D models and so on. But the owner team needs to be careful not to fall into the trap of becoming "the main reviewer" of the designer deliverables or becoming the entity that is in charge of quality (also known as the "quality police"). The key is to get the engineering company fully engaged and committed to produce high quality work for which the engineering company must have enough qualified engineers as well as adequate quality controls. The owner team should not be exposed to serious or multiple mistakes.

In general, the main responsibility for quality should stay with the designer so the checker (from the engineering company) would not need "to scrutinize every aspect of the document" [*6*] and as a general rule of thumb "the checker should only spend one tenth of the time spent creating the document" [*6*]. If the owner team receives documents with serious or multiple mistakes (or both) it typically means that the system is not working properly on the contractor side and needs to be addressed immediately. The owner team must help with quality checks, but needs to be assertive and have the necessary leadership skills to make sure that any significant issues in quality control are quickly and properly resolved by the contractor. Having the owner team cover for significant deficiencies in quality (due to poor quality work or poor quality control at contractor side) would be just "bandaids" and would not be sufficient.

Naturally, it is not necessarily easy to address performance issues, such as the quality or communication issues described above, but nevertheless it is imperative that such issues are quickly addressed and solved. That is one of the many reasons for which leadership skills, including assertiveness, are some of the most important qualifications for owner representatives in the project environment.

Most project work and deliverables are prone to quality issues. Some are relatively easy to detect (for instance, deficiencies in P&IDs, missing information in data sheets and so on) via limited owner reviews. However, some quality issues are more difficult to notice (or to notice on time, when something can be done about it) and therefore the owner needs to be more proactive and ask "open ended" questions. Examples of situations where action may be needed include the following:

- EPC is using its own software (or even special commercial software) and the owner does not know how good the software is or how proficient the EPC team is with the software (at a minimum a sample of the

CHARACTERISTICS OF GOOD OWNER REPS: LEAD

L is for **leadership**, as it requires special skills to lead the team in an environment in which most of the team members may work for a different organization; also leadership to take care, defend and explain the owner needs. Specific examples of the importance of leadership are given in several sections of this article.

E is for **experience** and **engineering knowledge**; including experience in the specific technology and role (both highly desirable), experience in capital projects, knowledge of the industry and applicable standards (including owner company standards).

A is for **assertiveness**, for the owner representative to be able to quickly recognize issues, help to identify root cause and propose and evaluate adequate solutions. Several specific scenarios in which the owner's assertiveness is critical are discussed in this article.

D is for **drive** and **dedication**. This refers to motivation and drive by the owner representative to succeed in a demanding role and his or her willingness to dedicate a significant amount of time required to perform the role properly. ❑

software results should be carefully checked)

- Not enough technical work is being done in equipment-bid evaluations because the focus is on cost or schedule, or both
- Vendor package documentation is not adequate in a number of issues (examples: P&IDs not drawn to standards; relief valve calculations or documents not adequate; incomplete line list; and so on)

Schedule & cost considerations

Quality was discussed in the previous section without acknowledging the fact that quality, cost and schedule are not independent from each other but are in fact heavily interconnected. If the owner is not properly involved in the project work, the consequence could be poor decisions that result in quality and reliability issues, delays or re-work (or both) either of which could result in serious schedule and cost impact.

The owner team needs to continuously monitor cost and schedule for a number of reasons, including verification that the EPC company progress estimates are accurate and correct. This is critical for milestone payments, to avoid late surprises, manage related contracts and so on. For a number of reasons (probably including human nature) there is a tendency to over-estimate progress and accordingly a clear need for a close involvement by owner on progress assessment (which requires the right experience and amount of involvement by the owner to be able to validate progress statements).

From a schedule viewpoint, another reason that the owner needs to be heavily involved is related to schedule delays and specifically the corresponding mitigation. The owner needs to make sure that the root-causes are properly identified so that the proposed mitigations are appropriate. The classic example is a project delay resulting in the typical "first reaction" of increasing staffing, sometimes without properly studying if that approach would work. In fact, there is an old saying in the engineering and construction business that "a woman can give birth to a baby in nine months but nine women cannot have a baby in a month" [*3*]. In reality, sometimes adding people to speed up things backfires, as it can add confusion, decrease productivity, affect morale and so on, and therefore results in even further delays.

Regarding cost, "money talks," so typically the need for the owner's active participation in cost monitoring and control is better understood. However, it is probably important to point out a common mistake in which owner teams assume that once a lump-sum or LSTK contract is signed, the cost is "fixed" and the owner does not need to worry about cost anymore. In reality, lump sum contracts do not give you a ceiling price but only a floor price [*1*] or "starting" price.

Performance & staffing issues

It is understood that the only way to achieve quality in a project is to put together a team of highly capable and motivated individuals that work as a team [*3*]. Neither the best company procedures nor the most sophisticated quality-management plans can, by themselves, ensure a good design [*5*]. "Only the commitment and pride of the individual project team members will provide a quality product" [*5*].

Sometimes owners fool themselves by thinking that once they engage a prestigious engineering company with "top notch" work processes, they are set and can take a "hands-off" or relaxed approach. Perhaps they do not realize that "It's the people — not the procedures and techniques — that are critical to accomplishing the project objectives. Procedures and techniques are merely tools to help people do their jobs" [*7*]. Experienced owner representatives know that engineering companies have high-quality individuals as core team members (the so-called A-teams), but when demand for their services peak, they need to recruit additional staff that are typically not fully familiar with the work-processes and that might not have the same level of experience and capabilities of the A-team members.

The owner team needs to watch for this and maintain high standards by making sure that non-performing individuals are removed from the project as soon as possible — again, not a comfortable task but something critical for project success.

Turnover of contractor resources is another important issue. It is typical for the owner to include some contractual requirements for the contractor to not remove certain key individuals from the project without the owner's permission [*8*], for example project directors, project managers, process and discipline leads, schedule leaders, maybe some key process or project engineers, and so on. However, more generic contractual requirements (that is, establish a maximum percentage of rotation per year for all project personnel) would be a good policy also, since excessive rotation at any level or in any discipline could be very traumatic for the project.

Staffing issues go both ways: for the project to be successful, sufficient and qualified owner representatives are required so that delays and re-work are avoided by getting owner's input on time at every step of the project. Qualified in this context means individuals with the technical knowledge and the capability to make decisions. It is not uncommon for owner organizations (whose main goal is to run the plants safely) to rotate owner representatives too often due to unexpected more urgent needs or other reasons (talent development plans, company policies, and so on). This can easily create serious problems for the con-

tractor [8] and the project.

The owner team needs to continuously monitor and rapidly address any performance or staffing issues. Some examples of that follow:

- EPC not properly staffed for the job. It could be a plain quantitative issue (that is, not enough people assigned or not enough in certain discipline) or qualitative (not enough people with the right qualifications)
- EPC contractor shows a lack of experience in certain topics (any time after award). There are two potential scenarios: that the EPC contractor recognizes the weaknesses (and does something about it, including asking for help from the owner) or that they do not realize or openly discuss the weaknesses and the owner subsequently finds out via the quality of the deliverables or the day-to-day interaction with the individuals performing the work. Each of those scenarios would present special challenges to the owner team and would need to be addressed quickly and carefully
- Specific person on the EPC contractor side producing poor quality work
- Entire team or sub-team on EPC contractor side producing poor quality work
- A person or a sub-team without the necessary focus on safety

Project-team performance is also affected by the so called "soft issues" such as people issues, cultural issues and corporate-culture issues. If not properly understood, the soft issues may affect the morale and the productivity of the project teams, or could create misunderstandings that would lead to quality issues or re-work. Some examples are as follows:

- Specific person on the EPC contractor or owner side is very difficult to deal with (creates problems)
- Misunderstandings due to cultural differences, typical practices and such things
- Confusions because of a language barrier (for instance, English as a second language)
- Confusion because of other cultural issues (examples: date nomenclature month/day/year versus day/month/year; comma versus decimal point, and so on)
- EPC not being careful enough with confidential information when dealing with vendors and other third parties
- In general, cultural differences that affect "the work environment as communication styles, management styles, expectations of managers and employees, decision-making processes, work styles and the importance of teamwork, and attitudes toward hierarchy, age and seniority" [9].

Intervention & risk management

A common misconception is that EPC lump-sum (LS) contracts "transfer" the risk to the contractor. It is true that some of the risk is "transferred" and that is a key reason for owners to select LS contracts. However, it does not mean that by having a LS contract the owner does not need to worry. The reality is quite different and actually a significant portion of the owner's role in capital projects is to identify early and properly manage and mitigate risks. Note that, although some risks are common to both owner and engineering companies, there are also some risks that are specific to each of these entities. Simple examples of the latter are risks associated with quality issues that would make the plant unreliable after a few years.

Note also that besides the fact that each entity has specific risks, the perception of risk by each entity is different. To illustrate the differences in risks and perceptions, let's consider a hypothetical $2-billion project that becomes a complete "fiasco". A $2-billion fiasco would hurt almost any company in today's very competitive environment but considering that the chemical and petrochemical industries are very capital intensive, a large petrochemical company would be more able to spread the risk over all the assets than an EPC company. On the other hand, if a typical EPC company (in a business which tends to be less capital intensive) was liable and forced to respond for such liability, it would lead them to significant economic challenges potentially including bankruptcy.

A special topic on intervention and risk management is related to the so-called "gray" areas. Specifically, owner teams need to be watching for items that don't clearly fit under a single discipline or items that are not well defined as those could easily "fall in the cracks". One special subset is related to activities that are typically handled inside the owner organization by a certain discipline but in the contractor by a different one, or topics that are handled by a certain discipline by FEED contractor and by a different one by the EPC contractor. Clearly those items become more prone to be missed or forgotten. A simple but classic example is in the relief-valves area, in which typically process engineers perform the scenario identification and preliminary sizing but for further development different companies have different disciplines to handle the work (that is, either process engineering or instruments group or piping group).

The owner team is responsible for intervening when things are not going in the right direction. Intervention needs to occur as soon as possible to avoid too much cost and schedule impact, therefore early detection is critical. To detect issues early, the best mechanisms are continuous interactions with the contractor (instead of passively waiting for deliverables for review) and asking a lot of "open ended" questions that would help the owner to understand how the work is progressing and what are the real capabilities of the individuals performing the work.

Bear in mind, however, that intervention is typically not a pleasant job, and therefore some owner team members would not feel comfortable doing so and would tend to postpone or avoid. This is another of the many reasons for which assertiveness and leadership are two critical competencies to properly perform the owner role in capital projects.

A special item related to intervention and risk management is scope improvement opportunities. Due to a number of reasons (very creative teams, different contractor company from previous stage, different owner team from previous stage and so on), it is possible that the design becomes challenged at different stages and that ideas for improvement are formulated, creating the possibility of "late"

changes and re-work. Late changes, even when they mean improved design, tend to create serious issues in projects. In fact, if not properly managed they could lead to chaos. However, the "no-more-changes mentality" although common and typically very appropriate, could also backfire if design problems are not addressed, or valid and valuable improvement opportunities are missed.

The right approach is to encourage critical revision of the design, making open channels available to discuss potential problems and to formulate ideas for improvement. At the same time, only changes that clearly meet project criteria should be allowed, such as "won't work" or "unsafe" or "extremely profitable opportunity." Needless to say that for a project to be successful, it needs to have a strong "management of change" procedure.

Contractual issues

Although the importance of clearly defining of scope and each party's responsibilities seems obvious, in real life it is not uncommon for projects to have significant challenges due to deficiencies in the contracts. Besides, even when the importance of these issues are well understood by all parties, there can still be disputes and issues because of the inherent difficulties in fully describing the entire scope of large and complicated projects in contractual documents. Also, experienced owner teams know that having clear requirements in a contract does not necessarily mean that such requirements will be incorporated in the design, so the best approach is to "trust but verify."

The following are examples, from the process-engineering arena that help to illustrate this topic. These are items that typically need to be performed in detailed design, but that may be disputed if not properly described and clarified in the "invitation to bid" (ITB) and contractual documents: 1) evaluation of thermal expansion and addition of any thermal relief valves; 2) additional restriction orifices resulting from detailed-design hydraulic calculations; 3) additional steam traps needed in the design, but not shown in FEL P&IDs; and 4) evaluation and proper resolution of surge issues (that is, hydraulic hammer).

There are a number of other contractual issues that could surface during the EPC phase that need active participation by the owner to achieve positive and quick resolution. Examples are given in the box above.

Hiring a PMC?

With so many important owner responsibilities and contributions and with limited resources, sometimes the solution appears to be obvious (especially for large projects): hire a project management consultant (PMC) company. This approach is quite common for large projects and definitely a step in the right direction compared to a hands-off approach due to lack of owner resources. However, by no means can this be considered a panacea that will solve all problems.

The need to hire a PMC company is almost a given for mega projects and other very large projects, as it is almost impossible for the typical owner company to properly staff such projects, not only in terms of simple headcount but also in terms of expertise and project execution capabilities. However, note that several of the fundamental issues discussed in the previous sections also apply to a PMC. For example, the timing considerations for a PMC are different from the owner company. Similarly to the EPC, the PMC would not have to "live with the consequences" through the plant's lifecycle.

Note that although a PMC could add a lot of value, it also adds complexity (at the end is another party with another set of goals), so hiring a PMC does not mean that the owner team is relieved of the responsibilities and can relax. The owner team will need to integrate well with the PMC team, and also properly manage the PMC to achieve project success.

If the above does not happen, it could result in additional confusion. For example, the EPCs could receive different or conflicting instructions from the owner and from the PMC, which could easily result in chaos if not rapidly addressed. There are a number of scenarios that could lead to different instructions from the owner and the PMC. The typical ones are poor integration and poor communication between owner and PMC, and lack of adequate training to the PMC team (so it would tend to do things the way the PMC company typically does them, instead of the preferred way for the specific project).

In summary, hiring a PMC could be quite helpful and is almost a must in very large projects, but it is not a perfect solution. It does not relieve the owner team of its responsibilities and actually requires good planning, management, leadership and assertiveness skills by the owner so that the PMC approach is effective and leads to project success.

A word of caution

Although the key message of this article is the need for very active involvement by the owner in project work to achieve project success, there are also some potential pitfalls that the owner team needs to be aware of, as follows:

- Owner representatives need to be careful not to express their opinion in something that they are not familiar with (that is, outside their area of expertise) since opinions might be "misrepresented" as owner instructions. The reader might think that only people who are arrogant

CONTRACTUAL ISSUES

There are a number of contractual issues that could surface during the EPC phase that need active participation by the owner to achieve positive and quick resolution. Examples are as follows:

- EPC sub-contracts key pieces of the work or many pieces, which results in additional challenges and opportunities for miscommunication, errors, quality issues and so on
- EPC contractor claims "significant" issues in the FEL package during their initial review
- EPC contractor actually finds "significant" issues in the FEL package during their initial review
- EPC contractor claims that certain "typical" FEL package documents are missing or that the degree of development is not what they expected (and bidded on)
- Conflicting information between the different multiple FEL package documents (although a good FEL package should clearly define priority of documents in case of discrepancies) ❑

or over-confident would fall into this trap, but in reality it is easy to get in trouble in this area, as EPC companies tend to ask questions on all kinds of topics, but it is almost impossible for an owner representative or even the entire owner team to have expertise in all areas

- EPC is no time for "wild guesses" as those guesses might be translated into procuring or building something, which would typically be very expensive to update. Instead of wild guesses, designers need good and reliable data to move forward
- One common issue is that the EPC contractor may have questions about the FEL package, but the owner team does not remember all the FEL details. The best approach to prevent this is to be proactive by keeping good documentation from the FEL phase, including clear and well-organized calculation records.
- Sometimes, the owner team receives too many documents to review, so it becomes a bottleneck. There are two types of scenarios, depending on the frequency of occurrence. Getting behind once in a while (due to workload peaks) is quite normal but still needs to be properly managed so that it does not create unnecessary problems, delays, claims or arguments. However, when the owner gets behind often, the issue needs to be addressed and corrected properly (by prioritizing work, getting additional manpower, working even longer hours and so on). Otherwise it could have a very serious negative impact on the project. An extreme example is when, due to the many things that occur simultaneously, the owner team does not seem to find enough time for critical reviews — needless to say, this could easily lead to disaster, so it needs to be properly corrected as soon as possible. Although it may sound impossible or even counterproductive, experienced owner representatives know that a good mitigation for the heavy workload is to collaborate and interact with the contractor on a day-to-day basis and discuss the deliverables while they are being prepared, instead of waiting to be literally "flooded" with unfamiliar documents to be reviewed
- The owner team may be pushed by circumstances (that is, unexpected studies, quality issues, confidential issues and so on) to be a "doer" versus "reviewer" during the EPC phase. This reduces the time that the owner team can dedicate to review and interact with the EPC, so it typically results in the issues described in the bullet above
- An owner representative doesn't have enough knowledge about a certain issue that he/she is asked to approve, review or discuss. A typical example is when owner representa-

tive is asked to visit a shop but the person does not have much experience with equipment fabrication, welding and so on

However, the biggest trap of all is not acting like the owner and letting the contractor work on his /her own. This could be called the "easy life" approach and becomes natural to owner representatives whose assertiveness and leadership skills are not the best. A rule of thumb is that if an owner representative thinks the job is "easy", he or she is likely not doing it right. Due to human nature, people who are not self-motivated tend to exert a minimum amount of effort; such an approach is a risky and expensive proposition for projects. Owner representatives need to be watching for those situations, they need to motivate their teams and make sure that the EPC team members are not only qualified, but fully engaged and committed to the project. However, if that is not achieved and things are not going well, the owner representatives also need to have the necessary assertiveness and courage to intervene when necessary. That intervention starts with proper day-to-day interaction, but may require more difficult actions such as removing certain individuals from the project or making drastic decisions, such as using to another engineering company. ■

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Understanding Boiler Circulation

Proper arrangement of drum baffling, sizing and location of dowcomers and risers will ensure a good natural-circulation system

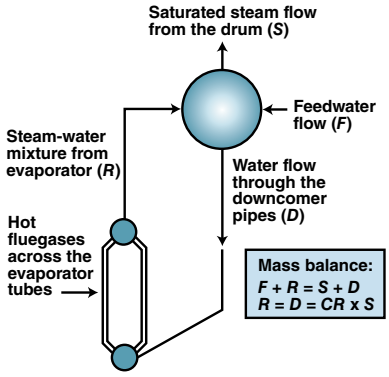

FIGURE 1. Boilers may operate using a variety of methods to circulate the steam-water mixture throughout the evaporator tubes. A typical natural-circulation system is shown here (CR = circulation ratio)

V. Ganapathy
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Boilers generate steam using different methods to circulate the steam-water mixture through the evaporator tubes. These methods include natural circulation (Figures 1, 2a–2c), forced circulation (Figure 3a), and a once-through design. Figures 3b, 4 and 5 show examples of a waste-heat water tube and fire-tube boilers with external downcomers and risers. Most boiler systems have evaporator tubes heated by hot fluegases produced either from the combustion of fuels (such as oil, gas or solid fuels,) or by kilns, furnaces, gas turbines or catalytic crackers, or by other hot gas sources (such as waste-heat boilers). Boiling occurs in the evaporator tubes, and generates wet steam.

The density difference between the colder water in the downcomers and the hotter steam-water mixture in the evaporator tubes ensures the circulation of the steam-water mixture back into the drum. External downcomers, as shown in Figure 2c, are unheated, while in package boilers (Figure 2b), they are internally located and are slightly heated by the fluegases.

In the steam drum, the mixture is separated into saturated steam, which flows out of the drum, and remaining water, which mixes with the incoming feed water and flows through the downcomers to start the circulation process once again.

Circulation ratio

The ratio of the mixture that flows through the system and the amount of steam generated is called the circulation ratio (CR). CR is obtained by an iterative process, which is discussed in detail in Ref. 1;. It is a function of steam pressure and hydraulic resistance of downcomers, risers, evaporator tubes and thermal head.

Generally steam pressure and CR are inversely related, so the higher the steam pressure, the lower the CR, and vice versa. Another important parameter is the steam quality, x, exiting the evaporator, which is simply 1/CR. Thus, if CR = 8, then x = 1/8 = 0.125, meaning that 12.5% of steam is generated in the evaporator tubes while the rest of the mixture is water. CR may be in the range of 20 to 30 for low-pressure boilers (100 to 600 psig), and about 8 to 15 for higher-pressure units, depending on the design.

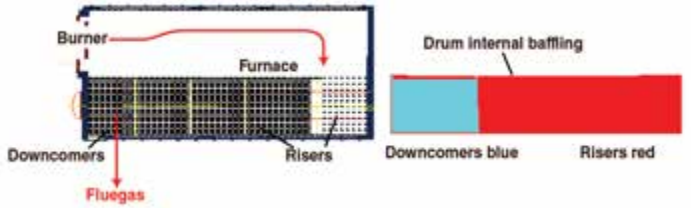
Note that CR usually represents an average circulation ratio. Keep in mind that CR varies with circuits depending on steam generation and any resistance offered by the system. In a boiler there can be several parallel circuits generating steam. For example, when hot fluegases flow across a bank of tubes, the first few rows will generate a large amount of steam due to the higher log mean temperature differential (LMTD) compared to the evaporator tubes at the cooler end. This will impact the CR.

Determining CR is only one part of the exercise. Once CR is estimated for a circuit, the engineer has to determine if the flow velocity inside the evaporator tubes will not cause separation of steam and water inside the tubes (particularly in horizontal evaporators) and must also determine if the heat flux in the circuit is low enough not to cause what is called departure from nucleate boiling (DNB) conditions.

If DNB conditions are likely, overheating and failure of the tubes can occur. Variables such as tube size, tube orientation, steam pressure, mass flow through the tubes and quality of the steam affect DNB. Charts and correlations are available for estimating the critical heat flux that can cause DNB conditions.

Natural-circulation boilers, such as package D-type boilers that are fired with oil, gas or solid fuels (Figure 2a), are widely used in the chemical process industries, petroleum refineries and power plants. Their capacity ranges from 20,000 to 300,000 lb/h with steam pressures from 100 to 1,500 psig. These are typically shop-assembled boilers in which the downcomers are inside the boiler and are heated (Note: In this design, the downcomers and risers are all inside the boiler and heated by the fluegases. However, a portion of the heated tubes at the cooler end of the boiler are designated as downcomers and are baffled inside the drum. The tubes at the hotter end are the risers).

For larger capacities, an elevated drum modular unit, such as the one shown in Figure 2c, is often more suitable, due to shipping considerations. This unit has external downcomers and risers, and all the evaporator tubes in the boiler bank are risers, unlike the smaller D-type boilers, in which some of the evaporator tubes can act as downcomers. This discussion is limited to natural-circulation units only.



FIGURES 2a (left) AND 2b (right). The baffles inside the steam drum, and downcomer tubes inside a typical package D-type boiler, are shown here

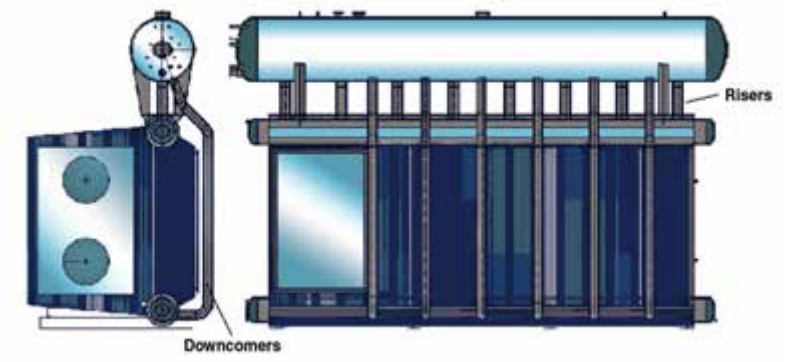


FIGURE 2c. In this D-type boiler with an external drum, downcomers and risers, feedwater from the economizer enters the steam drum and mixes with the water from the steam-water mixture from the riser tubes and flows through the eternal downcomers to the bottom of the evaporator tubes

Circulation calculations

For proper boiler operation, one has to ensure that there is adequate flow of the steam-water mixture inside the evaporator tubes to keep their tube-wall temperatures within metallurgical limits. If for some reason the flow is absent or inadequate or stagnation of flow has occurred, then the tubes can become overheated and fail. Users must carry out circulation calculations to ensure that there is proper circulation of the steam-water mixture through the evaporator. Ref. 1 describes the calculation procedure for determining CR in a natural-circulation boiler, and provides illustrative examples. Briefly, the basic steps are as follows:

Step 1. Thermal performance calculations must be carried out first, using the fuel analysis, excess air and the geometrical data of the furnace, superheater, evaporator and economizer tubes. The procedure for calculating thermal performance is also explained in Ref. 1. Typical tube-geometrty data for a D-type boiler and results for the thermal calculations can be found in Tables 1, 2 and 3, in the online version of this article (www.che.com).

Typical tube- geometry data for a D-type boiler is shown in Table 1, and results of the thermal calculations are shown in Table 2 (Note: All three tables for this article can be found in the online version of it, at www.che.com). Thermal calculations are carried out to obtain the gas-temperature distribution along the fluegas path and the energy transferred to each component in the system (such as the furnace, superheater, evaporator and economizer). The evaporator may be split into a few sections so that the energy transferred and steam generation in each section may be obtained. These data will be useful for carrying out the circulation-related calculations.

Step 2. Once the calculations in Step 1 are complete, a CR is assumed. The steam quality at the exit of the evaporator is then known, as well as the mass of steam-water mixture quantity flowing through the downcomer-evaporator-riser system, which is the product of CR and steam generated. If we assume a CR of 10 to start, and the steam generated in the boiler is 90,000 lb/h, then 900,000 lb/h of mixture flows through the downcomers, evaporators and risers, and the quality of steam at the exit of risers is 0.1.

Step 3. An energy balance is then carried out at the drum, to estimate the enthalpy of the water entering the downcomer tubes. The density of the water is computed. Note that the density difference between the downcomer water and steam-water mixture in the riser is responsible for circulation.

In this example, the enthalpy of the steam-water mixture at the evaporator exit is: 0.1 × 1,203 + 0.9 × 474.8 = 547.6 Btu/lb, where 1,203 and 474.8 Btu/lb are the enthalpies of saturated steam (h_v) and water (h_{fw}), which are obtained from the steam tables. If the feedwater enters the drum at, say, 350°F, enthalpy = h_{fw} = 322.5 Btu/lb, then the heat balance in the drum is calculated as follows:

$$h_{fw} + h_e \times CR = h_v + CR \times h_d \qquad (1)$$

where:

h_{fw} = enthalpy of the feedwater, Btu/lb

h_e = the enthalpy of steam-water mixture leaving the evaporator, Btu/lb

h_d = the enthalpy of the steam-water mixture entering the downcomers, Btu/lb

h_v = enthalpy of saturated steam leaving the drum, Btu/lb

Note: In the above equation, the steam generation is taken as unity and thus will not affect the energy balance:

$$900{,}000 \times 547.6 + 90{,}000 \times 322.5 = 900{,}000\, h_d + 90{,}000 \times 1{,}203 =$$
$$h_d = 459.5 \text{ Btu/lb}$$

With h_d = 459.5 Btu/lb, this corresponds to a water temperature of 476°F. This water will pick up additional energy in the heated downcomers. The downcomers are located in the cooler gas region of the evaporator section (where the energy pickup from the fluegas is not high). Thus, the downcomer water temperature is cooler than that of the mixture flowing in the riser and has a higher density, which forces the two-phase mixture through the evaporator tubes.

Nearly 95% of the energy from the fluegases is absorbed in the first 70–75% of the heating surface in the evaporator. As the last few rows do not absorb much energy, the water temperature in the downcomer tubes is cooler and the water density is higher than that of the hotter steam-water mixture in the riser tubes and this ensures the circulation process.

Step 4. Sizes, developed lengths and the number of bends of downcomer tubes and evaporator tubes are obtained from

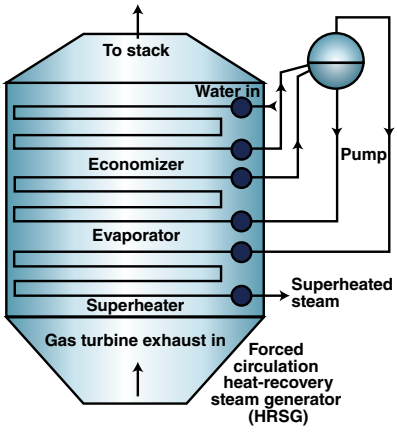
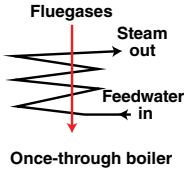


FIGURE 3a (above). In this forced-circulation boiler (generally seen with horizontal evaporator tubes), a circulation pump is used to suck water from the drum and ensure its flow through the evaporator tubes and back into the drum. The pump capacity determines the CR, which can vary from 3 to 8, depending on the designer's choice

FIGURE 3b (right). In this once-through boiler, there is no circulation system, so CR = 1. Water enters at one end and flows out as steam at the boiler exit. There are different considerations for designing this type of boiler, but that is beyond the scope of this article



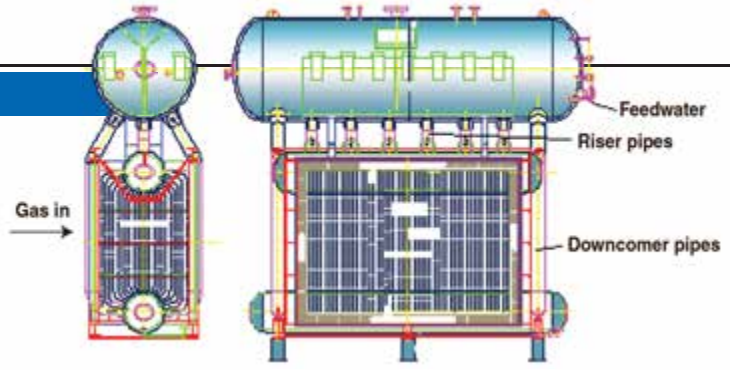


FIGURE 4. In this waste-heat boiler with external downcomers and risers, feed water enters the drum from the boiler feed pump or from an economizer. The water mixes with the water from the evaporator tubes and the mixture flows down the downcomer pipes to the bottom of the evaporator tubes. The CR, established by an iterative process, can vary from 5 to 40, depending on a variety of variables

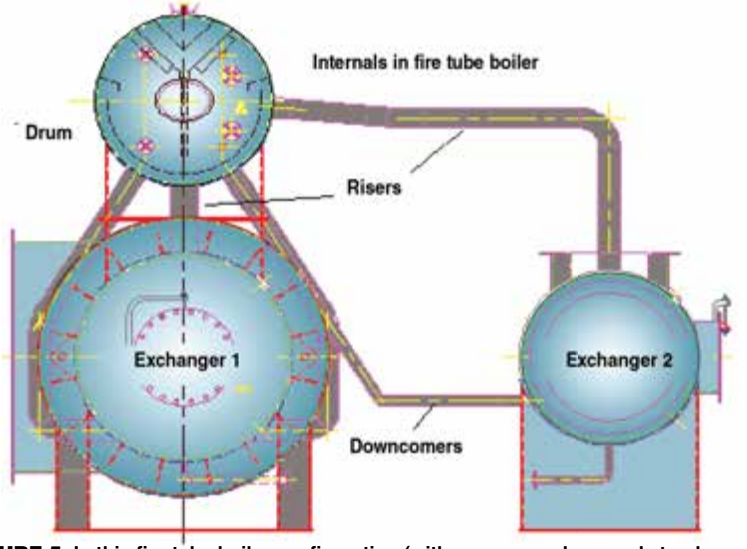


FIGURE 5. In this fire-tube boiler configuration (with a common drum and stand-alone downcomers and risers), the feedwater is admitted into the drum, where it mixes with the hot water from the risers and flows through the external downcomer tubes

the boiler drawings from which the various hydraulic losses in the circuits can be computed. These include:

- Thermal head available for circulation (this depends on the location of the drum)
- Friction loss in the downcomer tubes (this is due to the single-phase flow)
- Losses in evaporator tubes (this consists of friction losses, acceleration loss due to two-phase flow, and gravity loss due to varying quality along the evaporator height)
- Losses in the drum internals
- Losses in riser tubes in cases where external riser pipes are used

Charts for the calculation of various two-phase losses are available in Ref. 1. The total losses are matched with the available thermal head. If they match, then the CR assumed is correct. If they do not match, then another iteration is carried out to obtain the CR at which the available head matches the various losses. A computer program is usually used for these calculations.

If the CR is relatively low (say, in the single digits) and if the steam pressure is relatively high (say 1,500 psig or above), then DNB checks[1] may be carried out after obtaining the heat flux in each region. If the CR is low — for instance, in the single digits, such as 5–6, as in the case of high-pressure boilers operating above 1,500 psig — then efforts may be taken to revise the tube sizes of the risers and downcomers.

The actual heat flux in the evaporator tubes can be calculated from the thermal calculations results done earlier, using this relationship:

Actual heat flux = overall heat transfer coefficient × (the gas temperature – the saturated steam temperature)

One should ensure that the actual heat flux is far less than the allowable critical heat flux all along the evaporator tubes. Hundreds of correlations are available in the literature to determine the allowable critical heat flux.

The Macbeth correlation provided below in Equation (2) shows the relationship among the several variables and may give a high allowable flux. Using this correlation, two heat flux values are computed. One is the actual heat flux inside the tubes (determined from thermal calculations done by the boiler designer, based on the boiler fluegas velocity, heat transfer coefficient and tube geometry used). Then the allowable heat flux is estimated from charts or correlations available in the literature (based on the CR computed and the tube geometry, flow inside the evaporator tube and steam pressure.) One should ensure that the actual heat flux is far lower — for instance,

1. DNB checks ensure that the boiling process in the evaporator tubes is nucleate and not film boiling. Charts and correlations are available to do this evaluation, which is required if it is felt that the CR is low, as discussed in the text.

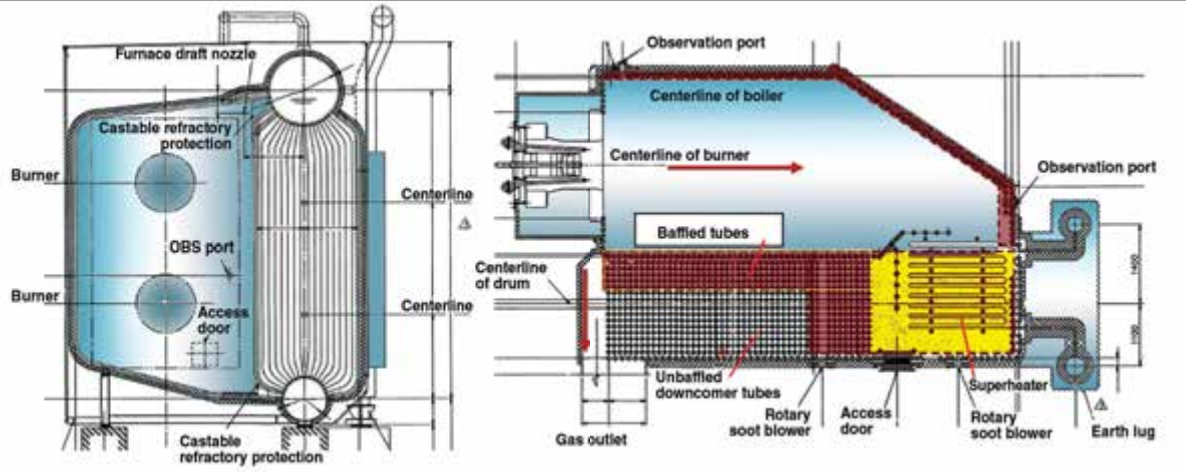


FIGURE 6a (top left) and b (top right). Shown is a typical arrangement of the boiler arrangement of a package D-type boiler with circulation problems. On the drum-baffling arrangment shown in Figure 6b, note the asymmetrical baffling with respect to gas-flow direction. This baffling system made it hard for many designated downcomer tubes to act freely as downcomers

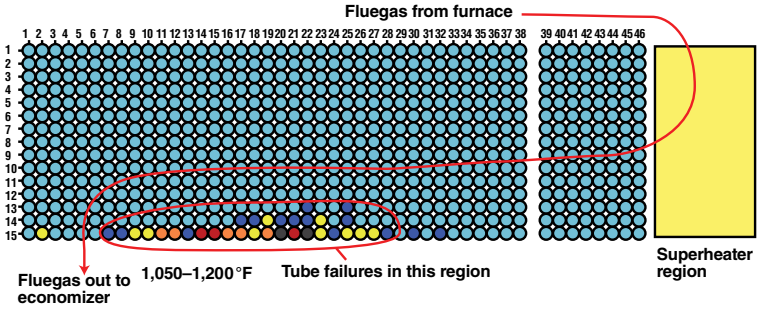


FIGURE 6c. This plan view shows the region where the tubes failed in the convection bank

at least 20–30% less than the allowable rate — to ensure that departure from nucleate boiler does not occur in the evaporator tubes. Boiler companies typically develop their own correlations based on their experience, the tube sizes and configuration used, and they routinely use safety margins when developing them.

$$q = 6{,}330\ h_{fg}\ d^{-0.1}\ (G/10^6)^{0.51}\ (1–x) \quad (2)$$

where:

q = critical heat flux, Btu/ft^{2}h
d = tube inner dia., in.
G = mass velocity of steam water mixture through tubes, lb/ft^{2}h
x = steam quality, fraction

Circulation issue, D-type boiler

Figures 6a and 6b show a boiler, fired with oil and refinery gas, generating 130,000 lb/h of superheated steam at 630 psig, and 750°F, which had an interesting problem. Tubes were thinning and failing at a location in the boiler bank shown in Figure 6b. There were two identical units in this plant and both were having this problem. Engineers were wondering why this region alone was facing this problem — not the hotter zone ahead of these tubes, or the tubes at the other end of the same cross-section (that is, in the same plane perpendicular to the gas flow direction), where one would expect the same gas temperature. As a consultant, I was asked to evaluate the design and suggest suitable solutions.

Analysis. The first step was to simulate the boiler performance using the tube geometry and furnace dimensions provided, to see if the exit gas temperature, superheated steam temperature, and water temperature leaving the economizer were all close to the measured field data. This step was designed to confirm that the model used to carry out the calculations of gas temperatures, overall heat transfer coefficients and actual heat flux were reasonable, and that the boiler was properly sized, as that may provide some indication of other issues such as fouling. The simulation gave the exit gas temperature from the evaporator and economizer as 798°F and 388°F, respectively, which matched the field data. Hence the simulation program results were used to study the circulation issue.

The evaporator section was broken up into four sections and the gas temperature, duty and steam generation in each section was calculated. It was found that the gas temperatures in the region where tubes were failing were ranging from 1,050°F to 1,200°F, as seen in Table 1b (found in the online version of this article, at www.che.com). Circulation calculations were carried out using these data. Typical results are shown in Table 2 (online). The heat flux q in the hottest gas zone of 1,300°F, given by Equation (3):

$$U(T_g–T_s)A_o/A_i = 9.5 \times (1{,}300–498) \times 2.5/2.24 = 8{,}503\ \text{Btu/ft}^2\text{h} \quad (3)$$

where:

q = heat flux, Btu/ft^{2}h
U = overall heat transfer coefficient, Btu/ft^{2}hF
T_g/T_s = gas and steam temperatures, °F
A_o, A_i = the tube outer and inner surface area, ft^2

This value of U is not high enough to cause DNB in normal boiling situations. Heat fluxes have to be in the range of 150 to 200,000 Btu/ft^{2}h before we can attribute DNB to the tube-failure problems in natural-circulation boilers with vertical tubes at this pressure.

Next, the drum internal arrangement was reviewed (Figure 6a). This diagram provided a clue to the problems that the plant was experiencing. In a typical D-type boiler with

fluegases flowing parallel to the drum over the boiler bank tubes, the drum baffling is designed as shown in Figure 2b. This will ensure that all the risers are in the hot gas section and downcomers are in the cooler gas section. Also, this type of baffling ensures that the tubes in any cross-section are acting either as risers or downcomers. In some large boilers, it may be necessary to have the drum at a separate location and feed the boiler evaporator tubes using an external downcomer system and collect the steam from the evaporator using an external riser system as shown in Figure 2c.

Figure 4 shows a waste-heat boiler with external downcomers and risers. The layout can vary depending on the boiler design adopted.

In a typical boiler, the tubes perpendicular to gas flow direction are symmetrically baffled. However in this boiler, by using this non-symmetrical baffling system, a portion of the evaporator tubes in the hot gas section in the same cross-section are forced to be downcomers, while some tubes in the same cross-section are under the baffle acting as risers. This was determined to be the source of the problem.

The fluegas temperature in the first row of downcomers is close to 1,400°F and the intense bubbling inside these tubes will force these tubes to act as risers, even though they are baffled as downcomers, due to the high heat transfer rate and the lower density of the steam-water mixture inside the tubes. Hence, these tubes — though not baffled — will still function as risers. Flow will continue through these tubes and circulation will be good.

In essence, these tubes have not failed, even though they are in the hot gas region. However, as the gas cools in the next nine rows, the gas temperature drops to about 1,200°F. This is the region where tubes at the far end of the furnace have failed.

These failed tubes have difficulty acting as downcomers due to the high gas temperatures; vapor formation at the inlet to the tube will still be intense and thus will prevent the flow of water in the downcomers. Also, the head available in the colder end of the boiler is not high enough to force the steam-water mixture through the tubes, since they have longer lengths and hence greater resistance to flow. The thermal head at the cool downcomer end is nearly the same as in these hotter tubes, and hence there is difficulty in forcing the steam-water mixture through these tubes.

Also, if you look at the typical gas-velocity profile in any cross section, it will be as shown in Figure 7, with the tubes in the middle receiving higher energy transfer compared to the end tubes. Thus, the end tubes that have failed do not generate sufficient steam-water mixture for the cold downcomer tubes at the rear to force the circulation of the steam-water mixture through these tubes. Simply put — these failed tubes are neither acting as good risers nor as good downcomers, and thus a stagnant vapor mixture may have formed in the tubes.

The vapor heat-transfer coefficient is very small compared to the two-phase boiling coefficient and hence the tube wall temperature will reach fluegas temperature, as there is not much of cooling inside these tubes due to the stagnant column of vapor in this region. Measurement of tube-wall temperatures near the failed region also confirmed the high temperatures.

The tubes within the same cross-section in the riser section (under the baffles and closer to the furnace) face no problem, as the head available for circulation is higher in baffled regions. The normal water level in the drum is typically at the drum center line and is at a higher elevation than the baffled section, so this ensures circulation. Hence, these tubes near the furnace act as risers. The mid-section is likely to have a higher steam formation than the ends due to the velocity profile and higher heat flux and hence have lower mixture density resulting in some circulation through these tubes.

Solution. The failed tubes have difficulty acting either as risers or downcomers due to the skewed baffling inside the drum. This is mainly due to the fact that many so-called downcomers are located in a very hot section. Stagnation of the flow is suspected in the failed tubes. If baffling inside the drum is done as shown in Figure 2a, the evaporator tubes under the baffles in the hot gas zone will be forced to act as risers and the cooler unbaffled section where the gas temperature drops to less than 900°F will act as downcomers, which will ensure good circulation of the steam-water mixture through the evaporator tubes. This solution is currently being implemented at the facility.

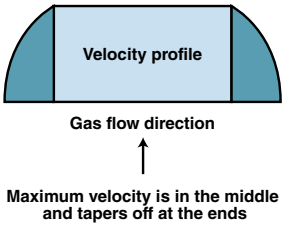


FIGURE 7. Shown here is a typical gas-velocity profile in a boiler bank cross-section. Tubes in the mid-section usually operate at higher heat flux compared to end section

Final thoughts

Before buying a boiler plant, engineers should review the boiler thermal performance, including circulation issues. Many plant engineers review information such as construction details, painting, duct thickness, structural integrity, code documents and so on, but few review the boiler's thermal performance calculations, drum-baffling system details or thermal performance and circulation issues. However, engineers should review these things before buying a new boiler plant, using either in-house expertise or third-party consultants. Getting a second opinion on thermal, process and performance issues can help the facility to purchase a better boiler and thus avoid unnecessary plant shutdowns and costly modifications later — an important consideration, given the fact that a boiler has a life of over thirty years. ■

Edited by Suzanne Shelley

Author

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A booming interest in separation technologies

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

Distillation and absorption are back. The AIChE Spring Meeting (San Antonio, April 28–May 2) proved it and the fall meeting to be held in November will muffle any doubting Thomases.

During the late 1970s and early 1980s, I spent appreciable time on acid-gas absorption. I knew the amine and hot-potassium-carbonate processes fairly well. I remember giving an absorption presentation at a large Canadian chemical engineering conference. Seven speakers gave seven presentations to an audience that was comprised solely of: the seven speakers. The applauses were less than deafening. Oh, how times have changed.

At the AIChE Spring Meeting, attendance at the Distillation and Absorption (D&A) sessions was historic. Henry Kister and Mike Pritchett did an excellent job of arranging the associated Topical Conference, but the waves of attendees who showed up for the Monday morning session honoring Tak Yanagi had the organizers gasping and scurrying for extra chairs. There were at least 100 attendees; generally, 40 is considered to be a good turnout. Tak is popular, but not that popular. Attendance at the D&A sessions was in fact very strong all week long. The neighboring Ethylene Producers Conference was attended by hundreds. The Safety Symposium was similarly popular.

The officers of the D&A group have generally found that the fall D&A sessions are not nearly as popular as the spring sessions. Therefore, for the AIChE Fall Meeting, they planned for four D&A sessions. To their surprise, 75 abstracts were received for the four sessions. The acceptance of all 75 abstracts would have limited each presentation time to less than a minute. The D&A organizers beseeched AIChE headquarters for extra sessions, and seven extra sessions were graciously afforded.

So, what happened? The answer is CO_2. Of the 75 abstracts that were received, 40 were regarding CO_2 absorption, adsorption, regeneration and membranic separations. The majority of the abstracts came from academia. Global governments, including the U.S. government, are pouring money into CO_2 research to reduce global CO_2 emissions.

Global distillation- and absorption-column work is possibly at the highest levels that I have seen in 40 years. Global membership in the FRI distillation consortium has been growing steadily since 2007. For plant owners and column operators, low U.S. natural gas prices have reduced the costs of feedstocks and energy. The new profitability is spurring investments.

The end of this high level of distillation and absorption activity is not in sight. U.S. oil production is at a very high level, especially because of hydraulic fracturing in Oklahoma and West and Central Texas. Six new pipelines are planned to bring light sweet crude oils to South Texas where the majority of U.S. petroleum refineries reside. Many of the columns of those refineries and downstream petrochemical plants will surely need to be revamped, to accommodate feedstock changes, or to effect capacity increases or to achieve energy consumption reductions.

Students in global chemical engineering programs should consider careers in "conventional" separation technologies and developing separation technologies. But they had better wear shades. Their futures will be bright. ■

Mike Resetarits

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53 Valves
54 Engineering Computers/Software/Peripherals
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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
2	17	32	47	62	77	92	107	122	137	152	167	182	197	212	227	242	257	272	287	302	317	332	347	362	377	392	407	422	437	452	467	482	497	512	527	542	557	572	587
3	18	33	48	63	78	93	108	123	138	153	168	183	198	213	228	243	258	273	288	303	318	333	348	363	378	393	408	423	438	453	468	483	498	513	528	543	558	573	588
4	19	34	49	64	79	94	109	124	139	154	169	184	199	214	229	244	259	274	289	304	319	334	349	364	379	394	409	424	439	454	469	484	499	514	529	544	559	574	589
5	20	35	50	65	80	95	110	125	140	155	170	185	200	215	230	245	260	275	290	305	320	335	350	365	380	395	410	425	440	455	470	485	500	515	530	545	560	575	590
6	21	36	51	66	81	96	111	126	141	156	171	186	201	216	231	246	261	276	291	306	321	336	351	366	381	396	411	426	441	456	471	486	501	516	531	546	561	576	591
7	22	37	52	67	82	97	112	127	142	157	172	187	202	217	232	247	262	277	292	307	322	337	352	367	382	397	412	427	442	457	472	487	502	517	532	547	562	577	592
8	23	38	53	68	83	98	113	128	143	158	173	188	203	218	233	248	263	278	293	308	323	338	353	368	383	398	413	428	443	458	473	488	503	518	533	548	563	578	593
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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

OCTOBER WHO'S WHO

Kehl

Diaz-Stringel

Morgan

Imbrogno

Morgan

Thomas Kehl becomes president and chairman of the executive board of **Coperian GmbH** (Stuttgart, Germany), which specializes in compounding and bulk-materials-handling systems.

Univar, Inc. (Redmond, Wash.), a global chemicals distributor, names *Sam Sutherland* vice president of global mining.

The Composites Group (Highland Heights, Ohio), a provider of composites solutions announces three promotions: *Hector Diaz-Stringel* is promoted to vice president of manufacturing operations, *Dwight Morgan* joins the company as vice president of sales and marketing, and *Marc Imbrogno* is promoted to the position of corporate director, market and product development.

Kwok-Keung (Amos) Au has joined the global peroxygens, water-treatment div. of **FMC Corp.** (Philadelphia, Pa.), as the technology applications manager for water treatment.

Jeff Morgan becomes the midstream oil-and-gas specialist with responsibility for the Rocky Mountain and Bakken territories of the West Region for **Netzch Pumps North America LLC** (Exton, Pa.).

Green chemistry innovator **GlyEco, Inc.** (Phoenix, Ariz.) has retained *Mike Sommer* as consultant. Sommer's primary focus will be on securing additional feedstocks for the company's Type 1 glycol-recycling operations. ■

Suzanne Shelley

BUSINESS NEWS

PLANT WATCH

Sibur and BASF sign longterm agreement for polymer additives
September 12, 2013 — Sibur (Moscow, www.sibur.com) and BASF SE (Ludwigshafen, Germany; www.basf.com) have signed a long-term cooperation memorandum to supply additives to be used for polymer production and processing at Sibur's production facilities. BASF will supply additives and also provide technical support.

Cabot and Risun open new carbon-black manufacturing plant in China
September 12, 2013 — Cabot Corp. (Boston, Mass.; www.cabot-corp.com) and joint venture (JV) partner, Risun Group, announced the completion and commissioning of a new carbon-black manufacturing facility in Xingtai, Hebei Province, China, with a capacity of 130,000 metric tons per year (m.t./yr). Cabot and Risun invested approximately $140 million in the new facility, with Cabot owning a 60% equity interest. Groundbreaking for the site was in April 2012.

Outotec-Hatch to deliver license for a potential alumina refinery in Abu Dhabi
September 5, 2013 — Outotec Oyj (Espoo, Finland; www.outotec.com) and Canada-based Hatch Ltd., as an unincorporated JV, were awarded a contract by Mubadala and Dubai Aluminium for a technology license as well as for the basic and detailed engineering of an integrated digestion and evaporation facility. The contract relates to the assessment of a potential alumina refinery development in Abu Dhabi. The contract price was not disclosed.

Gevo to produce bio-based *para*-xylene at newly opened biorefinery complex
August 27, 2013 — Gevo, Inc. (Englewood, Colo.; www.gevo.com) held a ribbon cutting ceremony for its demonstration-scale *para*-xylene plant in Silsbee, Tex. The *para*-xylene facility is located adjacent to Gevo's existing jet fuel plant in Silsbee, and establishes the site as a biorefinery that will serve the renewable chemicals and biofuels markets. Gevo is working with The Coca-Cola Co. (Atlanta, Ga.; us.coca-cola.com) to deliver a new production technology for renewable *para*-xylene, a key building block for renewable polyethylene terephthalate for beverage bottles. Research and development support for this plant was provided by The Coca-Cola Co. under a joint-development agreement.

Jacobs receives contract from CMPC for chlorine-dioxide plant in Brazil
August 27, 2013 — Jacobs Engineering Group Inc. (Pasadena, Calif.; www.jacobs.com) was awarded a contract by CMPC Group's Celulose Riograndense Ltda. for the design and supply of an integrated chlorine-dioxide plant for its pulp expansion project in Guaiba, Rio Grande do Sul, Brazil. The plant is anticipated to produce 55 m.t./d of chlorine dioxide. Under the terms of the contract, Jacobs is designing and engineering the plant, supplying key equipment and materials and providing technical services for plant erection, operator training, commissioning and testing.

Linde to build world's largest CO_2 purification and liquefaction plant
August 22, 2013 — The Linde Group (Munich, Germany; www.linde.com) has been awarded a contract to build the world's largest carbon dioxide (CO_2) purification and liquefaction plant for Jubail United Petrochemical Co., a manufacturing affiliate of Saudi Basic Industries Corp. The plant will be located in Jubail Industrial City, Saudi Arabia. The plant will be designed to compress and purify around 1,500 m.t./d of raw CO_2. The plant will also be capable of producing 200 m.t./d of food-grade liquid CO_2. Mechanical completion is set for 2015.

JGC receives contract for lube-oil blending facility in Indonesia
August 21, 2013 — JGC Indonesia, a wholly owned subsidiary of JGC Corp. (Yokohama, Japan; www.jgc.co.jp), has received a contract from the Indonesian subsidiary of Royal Dutch Shell for construction of a lubricating-oil blending facility in Indonesia. The lump-sum, turnkey contract calls for the engineering, procurement and construction work associated with a lubricating-oil blending facility with a production capacity of 120,000 m.t./yr.

Evonik announces expansion of oil additives in Singapore
August 20, 2013 — Evonik Industries AG (Essen, Germany; www.evonik.com) has announced an expansion of its Jurong Island, Singapore oil additives plant, to be completed in early 2015. With ongoing improvement and debottlenecking projects to be finalized in 2014, these optimizations and the expansion will nearly double the capacity of the oil additives plant.

MERGERS AND ACQUISITIONS

Evonik forms joint venture with Secar for lightweight composites
September 10, 2013 — Evonik Industries AG and Secar Technologie GmbH (Hönigsberg, Austria) established the LiteCon Advanced Composite Products JV on Sept. 4. The enterprise's aim is to mass-produce fiber-reinforced composite components for the automotive and aviation industries. The jointly managed JV is headquartered in Hönigsberg. Evonik will own 49% of the company's shares and Secar will own 51%.

Jacobs Engineering enters into merger agreement with Sinclair Knight Merz
September 9, 2013 — Jacobs Engineering Group Inc. has announced that it entered into a merger implementation agreement with Sinclair Knight Merz (SKM), a 6,500-person professional services firm headquartered in Australia, for approximately $1.2 billion. The transaction is expected to close by the end of the first quarter of 2014.

Eriez acquires Centriforce, a provider of coolant filtration systems
September 9, 2013 — Eriez Manufacturing Co. (Erie, Pa.; www.eriez.com) has announced the acquisition of U.K.-based Centriforce Ltd., a provider of advanced coolant filtration systems to the European metalworking industry. The Centriforce product portfolio will be integrated into Eriez's line of fluid recycling and filtration equipment.

A. Schulman acquires thermoplastics manufacturer Perrite for $52 million
September 3, 2013 — A. Schulman, Inc. (Akron, Ohio; www.aschulman.com) has signed a definitive agreement to acquire The Perrite Group, a thermoplastics manufacturing business, for approximately $52 million. Perrite's 2012 revenues were around $140 million.

Atlas Copco to acquire global vacuum supplier Edwards Group for $1.6 billion
August 20, 2013 — Atlas Copco AB (Stockholm, Sweden; www.atlascopco.com) and Edwards Group Ltd. have entered into an agreement where Atlas Copco will acquire Edwards, a global supplier of vacuum and abatement solutions, for an amount of up to $1.6 billion. The acquisition is an all-cash transaction that will utilize Atlas Copco's existing funds. ■

Mary Page Bailey

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FOR MORE ECONOMIC INDICATORS, SEE NEXT PAGE

2011 2012 2013

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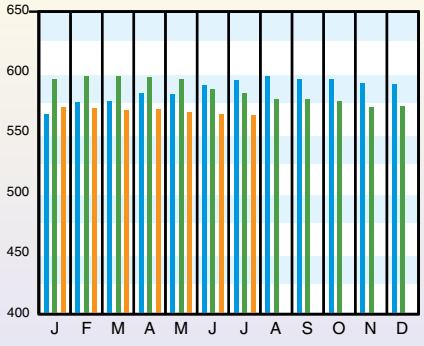
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Jul.'13 Prelim.	Jun.'13 Final	Jul.'12 Final
***CE* Index**	564.1	564.8	582.2
Equipment	682.0	684.1	708.5
Heat exchangers & tanks	620.7	626.7	652.0
Process machinery	655.0	654.4	664.7
Pipe, valves & fittings	861.8	859.3	911.3
Process instruments	407.5	410.1	424.3
Pumps & compressors	920.7	919.2	928.9
Electrical equipment	512.4	512.7	509.7
Structural supports & misc	729.8	730.9	757.8
Construction labor	320.2	317.3	324.1
Buildings	531.1	530.7	525.6
Engineering & supervision	324.6	323.9	328.0

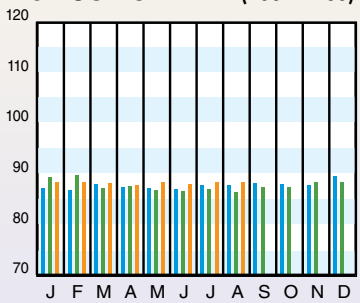
Annual Index:
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6



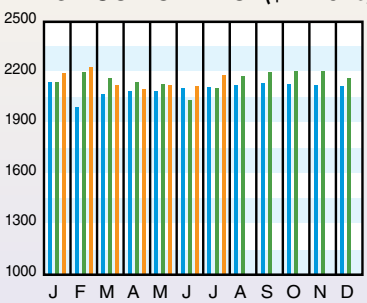
CURRENT BUSINESS INDICATORS

	LATEST			PREVIOUS			YEAR AGO		
CPI output index (2007 = 100)	Aug.'13	=	88.2	Jul.'13	=	88.2	Jun.'13	=	87.8	Aug.'12	=	86.4
CPI value of output, $ billions	Jul.'13	=	2,183.1	Jun.'13	=	2,116.5	May'13	=	2,124.9	Jul.'12	=	2,105.1
CPI operating rate, %	Aug.'13	=	74.6	Jul.'13	=	74.6	Jun.'13	=	74.4	Aug.'12	=	73.7
Producer prices, industrial chemicals (1982 = 100)	Aug.'13	=	301.0	Jul.'13	=	299.6	Jun.'13	=	304.0	Aug.'12	=	295.2
Industrial Production in Manufacturing (2007 = 100)	Aug.'13	=	96.0	Jul.'13	=	95.3	Jun.'13	=	95.7	Aug.'12	=	93.5
Hourly earnings index, chemical & allied products (1992 = 100)	Aug.'13	=	156.8	Jul.'13	=	156.8	Jun.'13	=	156.0	Aug.'12	=	155.7
Productivity index, chemicals & allied products (1992 = 100)	Aug.'13	=	105.1	Jul.'13	=	104.6	Jun.'13	=	104.7	Aug.'12	=	104.4

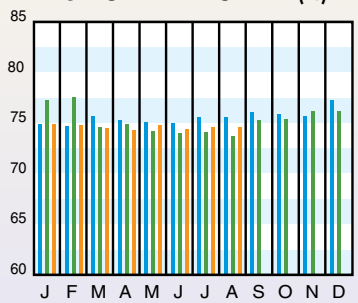
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

CURRENT TRENDS

Preliminary data for the July 2013 *CE* Plant Cost Index (CEPCI; top; the most recent available) indicate that the composite index decreased by 0.1% from the final June value. The value for the Equipment subindex fell, while those for the Construction Labor, Buildings and Engineering & Supervision subindexes all rose by modest margins from the June numbers. The July 2013 preliminary PCI index value stands at 3.1% lower than the corresponding final PCI value from July 2012. Meanwhile, the latest Current Business Indicators from IHS Global Insight (middle) were generally similar to the values from the previous month, with some values maintaining the same value as the previous month and others increasing slightly. ■

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