CHEMICAL ENGINEERING

February 2009

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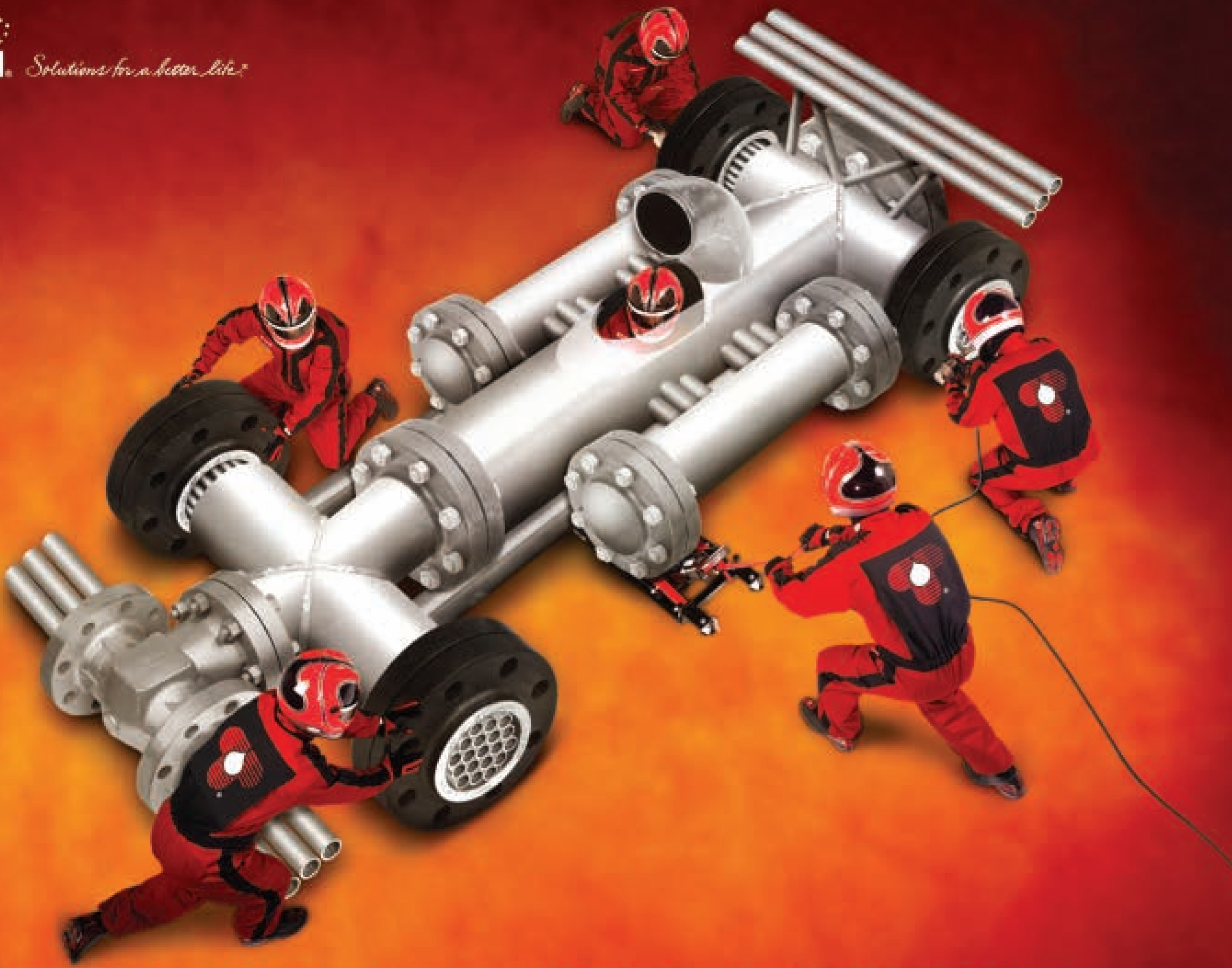

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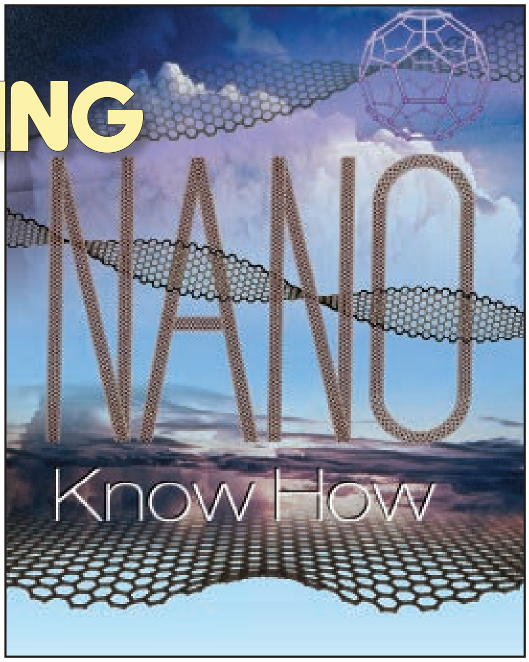


COMING IN MARCH

Look for: **Feature Reports** on Compressed Gas Cylinder Safety; Gas Applications in Fine and Specialty Chemistry; Combining Rupture Disk Devices with Safety Relief Valves; and Getting the Most Out of Your Rupture Disk; A **You and Your Job article** on Increasing Productivity by Using Web 2.0 Tools; A **Focus** on Milling & Grinding; **News articles** on Solar Energy; and Wireless Instrumentation & Networking; **Facts at Your Fingertips** on Membranes; An Achema **Show Preview**; and more

Cover: David Whitcher

Editor's Page

Is change coming to the CPI?

Although the inauguration of the U.S.'s 44th President is now fading into memory, the changes that Barack Obama's Administration will bring to the chemical process industries (CPI) are only beginning to reveal themselves. One thing is very clear, though: In these tough economic times, some very important policy issues are on the agenda with direct implications to our field. At the top of the list are plant security and energy, both of which are complicated by a longstanding public-relations challenge.

As change in Washington gets off the ground, an additional shift in leadership has already taken root on the other side of the Potomac River. In September of last year Cal Dooley, a 14-year member of the U.S. House of Representatives, officially took reigns as president and CEO of the American Chemistry Council (ACC; Arlington, Va.; www.americanchemistry.com). With first-hand appreciation for advocacy in Washington, Dooley is wasting no time reaching out to the new legislative and executive branches of government.

One of the first major steps Dooley took after the November election involves a letter and paper detailing ACC's clean-energy economic-recovery proposals, both of which were sent on December 18, 2008 to congressional leadership, committee leaders in both parties and the Obama transition.

Dooley writes, "The ACC supports new government investment in clean energy programs because these programs create jobs, improve the nation's energy security, and reduce greenhouse gas emissions. American chemistry also plays an important role in achieving these goals. Our industry produces materials that make the rest of the economy more energy efficient (for instance, insulation, light-weight vehicle parts). We also make materials used in clean energy technologies (for instance, wind turbines, solar panels, lithium-ion batteries). At the same time, American chemistry invests in technologies and services that improve the energy efficiency of our own operations (for instance, high efficiency combined heat and power systems). Given that our products are the fundamental building blocks of green technologies and energy efficiency, we believe our workforce is employed in 'green jobs'. It is imperative that these domestic jobs be retained and expanded."

From the Executive Summary of the American Recovery and Reinvestment Bill of 2009 that was released by the House of Representatives Appropriations Committee on January 16th, it appears that lawmakers heard at least part of ACC's message. The stimulus includes funding for science and technology, especially in the areas of renewable, clean energy. ACC's response, conveyed more recent letters to Congress, urges the committee to bulk up investments in gasification technologies, carbon capture and sequestration systems, and buildings and industrial efficiency programs. .

The key undertone to these and other recent policy discussions is simply science, which has often been the missing link where policy and public opinion come together. "We are committed to advancing our public policy priorities on science-based foundation. Our industry's commitment to solid research and good science has driven us to be among the most innovative sectors in the world. Science is the basis for our strong safety, health and environmental performance, and will continue to be the hallmark pillar of the business of chemistry," Dooley tells *CE*.

ACC has been very supportive of Obama's key Administration appointments, which in themselves indicate an outstretched arm to science. In a statement released during Senate confirmation hearings, Dooley used the word "exciting" to describe the selection of Nobel-prize winning physicist Dr. Steven Chu, for U.S. Secretary of Energy.

So while we cannot fully answer how change is coming to the CPI, there is some solace the premise that science is descending — in force — on Washington. ■

Rebekkah Marshall

Letters

Sharing personal achievement

I read with much surprise and pleasure your December 2008 issue, which covered *Chemical Engineering's* 2008 Personal Achievement Awards. The nomination is very meaningful for me coming from people in my team, and the selection is truly humbling. However, I wish to say that the efforts put in to improve the performance and protect the environment, and the record performances of the companies come as a result of team work. Most of the actual modification work has been done by the dedicated personnel in the two companies, namely See Sen Chemical Bhd and Malay-Sino Chemical Industries Sdn Bhd. Both are companies with histories spanning 30 years. But both companies have been breaking records every year for the past few years due to the tireless efforts of their dedicated technical personnel. Most of the improvements are from application of basic good engineering practice, like going back to basics, while also looking after the environment. This has really yielded dividends for the company. I see my selection for the award more as a recognition of all the effort put in by all the dedicated personnel in these two companies. There is much more for us to achieve.

Shyam Lakshmanan
See Sen Chemical Bhd and Malay-Sino Chemical Industries Sdn Bhd.

ACS Rubber division, call for papers

The Rubber division of the American Chemical Society (www.rubber.org) is now accepting online abstract submissions for the 176th technical meeting being held during the Rubber Expo, October 13–15, 2009, Pittsburgh, Pa.

Scheduled symposia include the following:

- Automobile Elastomers and Engineered Products
- Contributed Sessions
- Elastomeric Materials: Challenges in Pharmaceutical/ Biomedical Applications
- Elastomers for Wire & Cable Industry
- Filler Reinforcement of Rubber
- Mixing and Processing
- Natural Rubber and Natural Rubber-based Products
- New Commercial Developments
- Rubber Recycling
- Rubber Science
- Rubber Testing
- Science of Rubber Stabilization & Vulcanization
- Synthetic Rubbers and Synthetic Rubber-based Products
- Thermoplastic Elastomers
- Tire Technology

Abstract Deadline: April 10, 2009.

Postscripts, corrections

November 2008, Bringing the corrosion resistance of tantalum to off-the-shelf stainless-steel parts, p. 16: In the original version, the company location and Website are both misspelled. The corrected details are Tantaline (Lyngby, Denmark; www.tantaline.com).

Calendar

NORTH AMERICA

Coating 2009 West. The Powder Coating Institute (The Woodlands, Tex.). Phone: 832-585-0770; Fax: 832-585-0220; Web: thecoatingshow.com
Las Vegas, Nev. **Mar. 2–3**

Sustainability in Packaging 2009. IntertechPira Ltd. (Portland, Maine). Phone: 207-781 9800; Fax: 207-781 2150; Web: sustainability-in-packaging.com
Orlando, Fla. **Mar. 2–4**

Pittcon 2009. The Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, Inc. (Pittsburgh, Pa.). Phone: 412-825-3220; Web: pittcon.org
Chicago, Ill. **Mar. 8–13**

Renewable Energy World Conference & Expo. PennWell (Tulsa, Okla.). Phone: 918-831-9161; Fax: 918-831-9160; Web: renewableenergyworld-events.com
Las Vegas, Nev. **Mar. 10–12**

Strategize to Optimize — PAS Users Conference 2009. PAS, Inc. (Houston. Tex.). Phone: 281-286-6565; Fax: 281-286-6767; Web: pas.com/usersconference
Houston, Tex. **Mar. 9–11**

2009 AATCC International Conference. American Association of Textile Chemists & Colorists (Research Triangle Park, S.C.). Phone: 919-549-8141; Fax: 919-549-8933; Web: aatc.org/ice
Myrtle Beach, S.C. **Mar. 10–12**

Design & Manufacturing South. Canon Communications (Los Angeles, Calif.). Phone: 310-445-4200; Fax: 310-996-9499; Web: canontradeshows.com
Charlotte, N.C. **Mar. 11–12**

Interphex 2009. Reed Exhibitions (Norwalk, Conn.). Phone: 203-840-5533; Fax: 203-840-9533; Web: interphex.com
New York, N.Y. **Mar. 17–19**

2009 National Petrochemical & Refiners Association Annual Meeting. NPRA (Washington, D.C.). Phone: 202-457-0480; Fax: 202-457-0486; Web: npra.org
San Antonio, Tex. **Mar. 22–24**

ACS Spring 2009 National Meeting & Exhibition. American Chemical Society (Washington, D.C.). Phone: 781-273-3322; Fax: 781-273-6603; Web: acs.org
Salt Lake City, Utah **Mar. 22–26**

FIATECH 2009 Technology Conference & Showcase. FIATECH (Austin, Tex.). Phone: 512-232-9600; Fax: 512-232-9677; Web: fiatech.org
Las Vegas, Nev. **Apr. 6–8**

2009 Water Security Congress. American Water Works Association (Denver. Colo.). Phone: 303-794-7711;

Fax: 303-347-0804; Web: awwa.org
Washington, D.C. **Apr. 8–10**

54th ISA Analysis Division Symposium. The International Society of Automation (Research Triangle Park. N.C.). Phone: 919-549-8411; Fax: 919-549-8288; Web: isa.org/analysissymp
Houston, Tex. **Apr. 19–23**

Process Technology for Industry West. Canon Communications LLC (Los Angeles, Calif.). Phone: 310-445-4200; Fax: 310-996-9499; Web: ptxwest.com
Anaheim, Calif. **Apr. 23–24**

2009 AIChE Spring National Meeting. American Institute of Chemical Engineers (New York, N.Y.). Phone: 203-702-7660; Fax: 203-775-5177; Web: aiche.org
Tampa, Fla. **Apr. 26–30**

EUROPE

9th European Gasification Conference. Institute of Chemical Engineers (Rugby, U.K.). Phone: +44 01788 578214; Fax: +44 01788 560833; Web: icheme.org/gasification2009
Düsseldorf, Germany **Mar. 23–25**

LogiChem Europe 2009. Worldwide Business Research (London, U.K.). Phone: + 44 (0) 20 7368 9465; Fax: + 44 (0) 20 7368 9401; Web: logichemeurope.com
Düsseldorf, Germany **Mar. 31–Apr. 3**

Interkama. Deutsche Messe (Hannover, Germany). Phone: +49 511 89-0; Fax: +49 511 89-32626; Web: hannovermesse.de
Hannover, Germany **Apr. 20–24**

ASIA & ELSEWHERE

Wetex 2009 — Water, Energy Technology and Environment Exhibition. Dubai Electricity & Water Authority (Dubai, U.A.E.). Phone: +971 4 324 44 44; Fax: +971 4 324 81 11; Web: wetex.ae
Dubai, U.A.E. **Mar. 10–12**

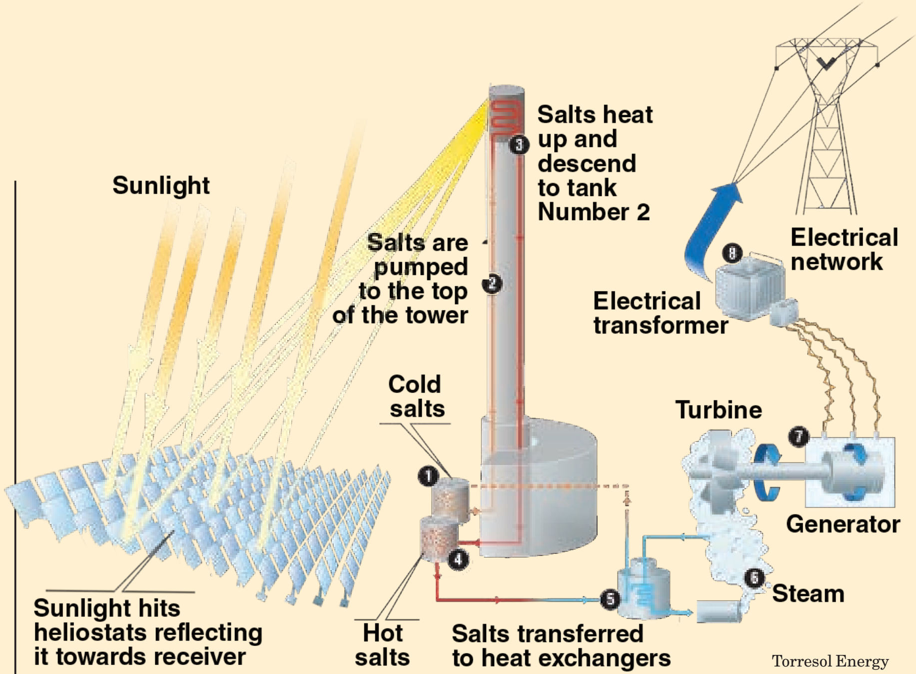
ARTC 12th Annual Meeting, Refining and Petrochemical. Incisive Media Ltd. (London, U.K.). Phone: +44 (0) 207 004 7576; Web: gtforum.com
Kuala Lumpur, Malaysia **Mar. 10–12**

16th Middle East Oil & Gas Conference & Exhibition. Arabian Exhibition Management WLL (Manama, Bahrain). Phone: + 973 17 55 00 33; Fax: + 973 17 55 32 88; Web: meos2009.com
Manama, Bahrain **Mar. 15–18**

Powder World 2009. China Powder Technology Association (Beijing, China). Phone: 010-88365655 ; Fax: 010-68361726; Web: powderworld.com
Beijing, China **Apr. 1–3** ■

Kate Torzewski

Construction to begin on a large solar plant in Spain



Torresol Energy

Thanks to a €171-million financing deal, construction can begin on what is claimed to be the world's first utility-grade solar power plant with central tower and salt receiver technology. When the so-called Gemasolar plant — located in Fuentes de Andalucia, Spain — is operational in 2011, it will produce 17 MWe of power, reducing CO_2 emissions by more than 50,000 metric tons per year (m.t./yr) that would be released by a conventional power plant of the same capacity.

The Gemasolar plant (diagram) will consist of 2,500 heliostats, which will track the sun and focus sunlight to a receiver at the top of a tower. There, 95% of the radiation is absorbed and converted to thermal energy, which is used to heat molten salts (potassium and sodium nitrates). The hot salts descend to a tank where it is stored at about 500°C. In a second loop, the molten salt passes through a heat exchanger. and the energy is used to produce steam, which drives a turbine for generating electricity. The molten salt's storage capacity is designed to enable power generation for 15 hours without sunlight.

Gemasolar is a project of Torresol Energy S.A. (Madrid, Spain; www.torresolenergy.com), a strategic alliance between Sener Ingeniería y Sistemas (Madrid; www.sener.es) and Masdar (www.masdaruae.com), Abu Dhabi's renewable-energy initiative. The engineering, procurement, construction contract has been awarded to a consortium, including Sener and AMSA, an ACS Cobra (Madrid; www.grupocobra.com) subsidiary. Sener will provide the technology, the detailed design and commissioning of the plant.

This centrifugal reactor/separator speeds up biodiesel production

A continuous process for producing biodiesel that has a residence time of about one minute, versus several hours for a conventional batch process, has been developed at Oak Ridge National Laboratory (ORNL; Oak Ridge, Tenn.; www.ornl.gov). The process uses a centrifuge for simultaneous synthesis of biodiesel and separation of the biodiesel from the glycerol byproduct. ORNL has done laboratory tests and is collaborating with biodiesel producer Nu-Energie (Surgoinsville, Tenn.) to do a pilot test at the Nu-Energie facilities later this year.

The key to the process is a Couette reactor/separator, a type of centrifuge that until now has been used only in the laboratory, says Costa Tsouris, a research engineer with ORNL. Food-grade soy oil and sodium methoxide (a mixture of methanol and sodium hydroxide) are fed separately into the reactor and rapidly mixed at 3,600 rpm. The reaction time is approximately 1 min, at which point the lighter methyl esters (biodiesel) and heavier glycerol are separated by the centrifugal action. The biodiesel yield for a 5:1 oil-to-methoxide ratio is about 95%, with less than 1% carryover of either phase into the other, he says. Current work is focused on increasing the yield.

Initially, the researchers were working with a conventional centrifugal contactor, but the residence time was too short at the 3,600-rpm speed required for thorough mixing, says Tsouris. "The Couette unit provides a residence time of about one minute," he says. He adds that the reactor/separator can be scaled up to production size and promises to reduce the size of the production equipment to well below 10% of that used in a conventional batch operation.

A new bioplastic

Up to now, the main plastic produced from renewable resources has been polylactic acid (PLA), which is derived from corn starch. However, because PLA does not have the same level of performance as petroleum-derived plastics, PLA has not been actively adopted by certain industries, according to Teijin Ltd. (Tokyo, Japan; www.teijin.co.jp/english). The company plans to change this situation with the commercial launch, later this year, of a new heat-resistant bioplastic, dubbed Biofront. Biofront is a stereocomplex PLA made with high-purity L- and D-lactate, which has a melting point of 210°C — significantly higher than the 170°C for conventional PLAs — and "rivals" that of polybutylene terephthalate (PBT), says the firm.

Teijin is currently operating a 200-ton/yr Biofront pilot plant. It recently acquired a 1,000 ton/yr PLA demonstration plant from Toyoto Motor Corp. (Tokyo); this new facility is expected to produce Biofront later this summer. A 10,000-ton/yr Biofront plant is also expected to be completed in 2010.

Note: For more information, circle the 3-digit number on p. 62, or use the website designation.

Final specs for SIF

Last month, the Fieldbus Foundation (Austin, Tex.; www.fieldbus.org) released the latest device-development solutions for its Foundation for Safety Instrumented Functions (SIF) technology, which includes the Foundation for SIF final Technical Specification package, SIF Interoperability Test Kit (ITK) and updated DD (Device Description) Library with SIF function blocks. The new technical specification defines analog input (AI) blocks for fieldbus transmitters and other SIF devices. Future updates to the specification will include digital output (DO) blocks.

Drought-tolerant corn

First results have been achieved from a plant biotech collaboration between BASF Plant Science (Limburgerhof, Germany; www.basf.com/plant-science) and Monsanto Co. (St. Louis, Mo.; www.monsanto.com) for a drought-tolerant corn. The product has moved into the final phase prior to an anticipated market launch early next decade, and Monsanto has submitted the product to the U.S. Food and Drug Admin. (FDA; Washington, D.C.) for regulatory clearance.

Drought-tolerant corn is designed to provide farmers with yield stability during periods when water supply is scarce by mitigating the effects of water stress within a corn plant. Field trials for the new corn met or exceeded the 6–10% target yield enhancement over the average yield of 70–130 bushels per acre in some key drought-prone areas of the U.S., says BASF.

A new syngas catalyst passes pilot tests . . .

Mitsunori Shimura and colleagues at the R&D Center of Chiyoda Corp. (Yokohama, Japan; www.chiyoda.co.jp) have developed a new catalyst for producing a synthesis gas (syngas; hydrogen and carbon monoxide) from steam reforming of methane. The catalyst consists of precious metals selectively loaded on the surface of the firm's commercial, egg-shell-shaped support, which results in an effective utilization of the costly metals.

The catalyst has been demonstrated in a pilot reformer (single, 12-m long tube with 110-mm dia.), which showed stable, on-stream operation for 7,000 h, with minimal carbon formation (less than 0.1 wt.%) on the catalyst. With a feed of natural gas (85 vol.% CH_4), and typical operating conditions of 900°C (outlet temperature), 1.9 MPa (gauge) and a molar feed ratio of CH_4:CO_2:H_2O = 1.0:0.4:1.15, the new catalyst produced a syngas with H_2-to-CO mole ratio of 2.0, making it especially suitable for gas-to-liquids (GTL) applications, or for the production of oxo-alcohols (such as *n*-butanol) and acetic acid, says the company. In laboratory trials, the catalyst has also shown 1,000-h of operation, without deactivation, for producing syngas with H_2-to-CO ratios of 1.0.

The catalyst and associated syngas-production process are being developed for a national GTL project coordinated by JOGMEC (Japan Oil, Gas and Metals National Corp.). A 500-bbl/d GTL plant is under construction with startup later this year.

. . . and a Ni-based syngas catalyst promises to slash reformer size and costs

Keiichi Tomishige, an associate professor at University of Tsukuba (www.ims.tsukuba.ac.jp), has developed a new high-performance catalyst for the highly efficient production of syngas, with support from the New Energy and Industrial Technology Development Organization (Kawasaki, both Japan). The nickel-based catalyst is selectively impregnated with small amounts of precious metals (Pt, Pd and Rh) on the surface. By performing the impregnation sequentially, rather than by conventional co-impregnation, Tomishige is able to control the structure of bi-metallic (Ni and precious metal) particles on the surface. This leads to active sites that accelerate both exothermic and endothermic reactions, resulting in the suppression of hot spots and carbon formation. The catalyst is also less prone to deactivation by oxidation of Ni, he says.

Because of the enhanced reactivity, Tomishige estimates that reformers operating with the new catalyst can be one-fourth the size of a conventional reformer with the same production capacity. And the cost of the catalyst is expected to be significantly lower due to the use of predominantly nickel with reduced amounts of precious metals.

The researchers are planning to scale up their work and apply the catalyst technology to the oxidative-reforming of other hydrocarbon feeds, such as city gas, gasoline, methanol and kerosene, with the aim to produce H_2 for fuel cells.

A pilot-step closer to second-generation biofuels

Lurgi GmbH (Frankfurt, Germany; www.lurgi.com) is building a pilot plant to demonstrate the viability of its three-stage bioliq process for producing liquid fuels from biomass. The pilot plant — an entrained-flow gasifier for the production of synthesis gas — will be located at the Karlsruhe Research Center (FZK; Germany; www.fzk.de), and is part of a joint project with the Karlsruhe Institute of Technology (KIT).

In the first step of the bioliq process, a fast pyrolysis process (operating at 500°C) converts biomass into a transportable, liquid intermediate product (bioliqSynCrude) whose energy density is 13–15 times higher than that of straw. The bioliqSynCrude is then preheated to around 80°C, pressurized and fed to the bioliq gasifier, where it is converted (at above 1,400°C) into syngas. In the final step, the syngas (produced at high pressure) is purified and fed to a synthesis unit for conversion to fuels.

The bioliq gasifier — developed on the basis of Lurgi's proprietary Multi-Purpose Gasifier (MPG) — is equipped with a castable, lined cooling screen that is cooled with pressurized water, and whose internal surface is protected from corrosion and erosion by a layer of slag. Crude syngas and slag are drawn off via a quench at the bottom of the reactor.

The fast pyrolysis pilot plant — the first step of bioliq — was commissioned last year at KIT; startup for the bioliq gasifier is planned for the Fall of 2011.

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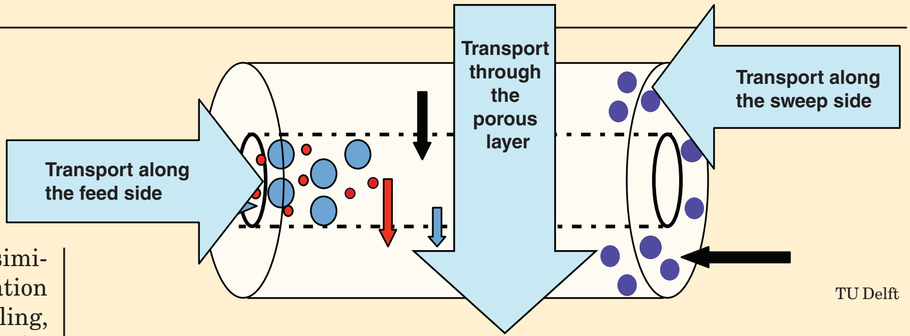


TU Delft

Progress on a promising separation technology

For separating two components with similar volatilities, extractive distillation is typically used, whereby a high-boiling, non-volatile solvent is added to "break the azeotrope" — a process that is both energy intensive and often involves the use of hazardous solvents. In an effort to reduce the energy requirements and avoid the use of hazardous solvents used in extractive distillation, an alternative separation technology, called frictional diffusion (FricDiff) is being developed by a consortium of academic (TU Delft and TU Eindhoven) and industrial partners (Akzo Nobel, Shell Global Solutions, Bodec, FIB Industriële Bedrijven BV and Purac), with financial support from Senter-Novem (all Netherlands).

FricDiff is based on the difference in diffusion rate of two components when diffusing through a third component (sweep gas). In a FricDiff unit, the vapor mixture flows through the tube side of a porous, stainless-steel cylinder, while the sweep gas flows counter currently on the shell side. Because heavier components in the feed experience more friction with the sweep gas in the porous layer, lighter components diffuse at a higher rate into the shell side. As a result, the vapor emerging from the tube side is enriched with the heavy component. Enrichments of 65–70% have been achieved in a single-tube FricDiff unit for isopropanol-water and helium-argon mixtures; however, "the balance between enrichment and recovery is a major challenge we are investigating," says Aylin Selvi, a doctoral student at the Process & Energy Laboratory, Delft University of Technology (www.tudelft.nl). Computer simulations set up by TU Eindhoven indicate that 90% enrichments are possible when operating with an overpressure of sweep gas, she says.

Last month, the engineering work was completed for a scaled-up test unit, which incorporates seven FricDiff tubes. This test unit will be operated at TU Delft starting April.

Sonicating slurries speeds soil remediation

Ultrasound has been applied, with limited success, for the remediation of contaminated soil. Up to now, the approach has been to first extract the contaminant from the soil into a liquid, which is then passed through a sono-reactor where the contaminants are destroyed by high temperatures and pressures (more than 5,000K and 1,000 atm) generated by cavitating bubbles. A new process developed by a team from CSIRO Materials Science and Engineering (Lindfield, Australia; www.csiro.au), in which flowing slurries are passed through a sono-reactor, has been shown to be 100-times faster than liquid-based methods.

The increased speed is believed to be the result of bubbles that nucleate and grow on the surface of the slurry particles. Instead of imploding symmetrically, as in liquids, these bubbles collapse toward the particle, forming a high-speed jet that impacts on the solid surface, explains CSIRO researcher Anthony Collings. Any substance adsorbed to the solid surface bears the brunt of this implosive energy, and the temperature rise is sufficient to pyrolyze the pollutant. The heat transfer rates in these bubbles — typically about 50 µm in dia. at the moment of collapse — are so high that any decomposition products from the pyrolysis reaction are very rapidly quenched, eliminating the possibility of recombination reactions. The team has confirmed that radical formation, which plays an important role in conventional sonochemistry, does not occur in slurries, and that pyrolysis is the dominant process, says Collings.

The team has conducted a series of studies with samples over a wide range of persistent organic pollutants (POPs) adsorbed on glass beads, and has progressed to pilot-plant scale. Sonication at 20 kHz with a power of 150 W leads to a 90% reduction of a polychlorobiphenyl after 1.5 min, and 99% reduction after 7 min (97% reduction of hexachlorobenzene after 10 min), with no traces of breakdown products. Similar results are obtained for clays contaminated with herbicides and total petroleum hydrocarbons. The pilot-plant studies are aimed at optimizing the process and confirming the low operating expenses suggested by small-scale experiments and the practicality of a transportable treatment facility.

Furanics

Royal Cosun (Breda; www.cosun.com) and Avantium (Amsterdam, both Netherlands; www.avantium.com) have started a two-year collaboration to develop a specific process for the production of a new generation of bioplastics and biofuels — tradenamed Furanics — from selected organic waste streams. For a number of years, Avantium has been developing Furanics, which can be produced from sugars and other carbohydrates from biomass. These bioplastics can be produced cheaper than petroleum-based materials, says Avantium.

Single-site catalyst

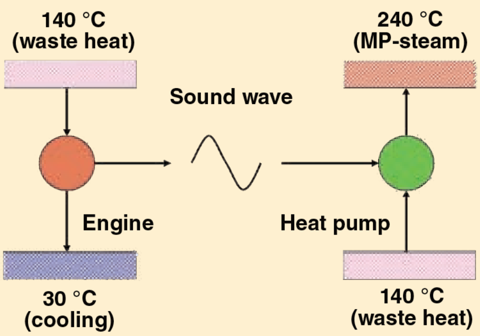
Last month, LyondellBasell Industries (Rotterdam, Netherlands; www.lyondellBasell.com) launched a new *Avant* M single-site catalyst system, which extends the performance capabilities of its *Metocene* polypropylene (PP) production technology. The new catalyst extends the range of homopolymer, random and impact copolymer grades by offering performance from very low to very high melt flowrates, while maintaining "outstanding" levels of homogeneity, transparency and other features of single-site catalysts, says the firm.

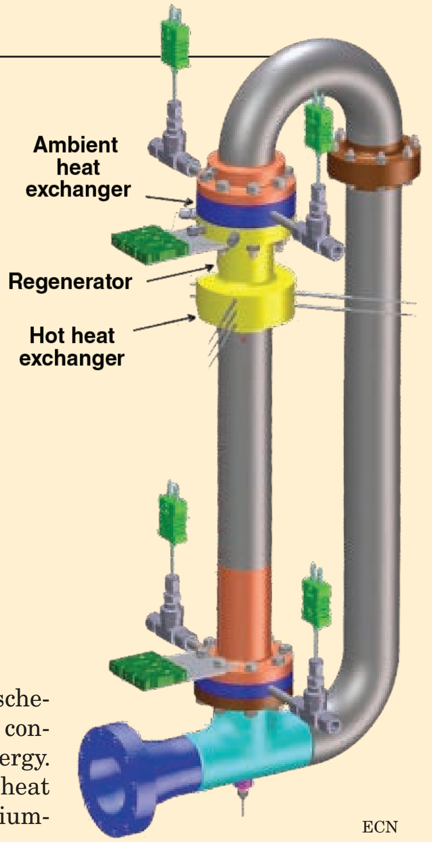
PA-11 for gas pipelines

The U.S. Dept. of Transportation Pipeline and Hazardous Materials Safety Admin. (PHMSA; Washington, D.C.; http://phmsa.dot.gov) published a final rule — effective January 23, 2009 — to amend 49CFR Part 192 to increase the maximum allowable operating pressure (MAOP) for Polyamide-11 (PA-11) pipes from 100 psig to 200 psig in

(*Continues on p. 16*)

A sound way to reuse low-temperature waste heat





ECN

In a so-called thermoacoustic engine, researchers from the Energy Research Center of the Netherlands (ECN; Petten, Netherlands; www.ecn.nl) have achieved a record efficiency in the conversion of heat to sound, improving the existing record of 41% to 48% of the maximum possible efficiency (Carnot efficiency). The engine is being developed as a way to utilize the huge quantities of waste heat, which normally cannot be reused because the temperature level is too low and is thus released to the environment. ECN is working with two equipment manufacturers — Bronswerk Heat Transfer B.V. (Nijkerk; www.bronswerk.nl) and Dahlman (Maassluis, both Netherlands; www.dahlman.nl) — to develop a system that uses a thermoacoustic heat pump driven by a thermoacoustic engine to upgrade waste heat.

The thermoacoustic engine is composed of three main parts (diagram, right): a thermodymamic part, consisting of a regenerator, two heat exchangers and a thermal buffer tube; an acoustic network, consisting of an acoustic compliance and an inertance; and a resonator. The thermodynamic part and the acoustic network are placed in a torus configuration. In operation (schematic, left), the thermoacoustic engine converts thermal energy into acoustic energy. This acoustic energy is then used in a heat pump to upgrade waste heat into medium-pressure steam, for example.

The prototype engine operating at ECN has achieved the record efficiency when driven by heat at high (500–600°C) temperatures. The next step is to extrapolate this performance to engines that operate at much lower (100–150°C) temperatures, says project leader Simon Spoelstra. An integrated laboratory system (engine plus heat pump) that delivers the required performance under relevant industrial conditions is planned for operation in 2010.

Commercialization nears for producing cartenoids from engineered yeasts

In late 2009, Microbia PE, Inc. (Lexington, Mass.; www.microbia-pe.com) will begin commercialization of its initial carotenoid products. Microbia plans to produce β-carotene, astaxanthin, zeaxanthin, cathaxanthin and lutein — all five carotenoid products that currently have significant commercial value. These carotenoids have primary applications as food ingredients, dietary supplements and animal feed ingredients.

Though chemically identical to carotenoids that are currently on the market, this firm's products will be made by fermentation of natural raw materials, such as sugar and vegetable oils, rather than by conversion from petrochemical-based materials.

Microbia CEO Richard Bailey explains that projected product costs are at least on par with products from the lowest-cost, chemical-synthesis manufacturers today. Furthermore, "for some of the more complex carotenoids with greater chirality," he says, "we believe our costs will be significantly lower."

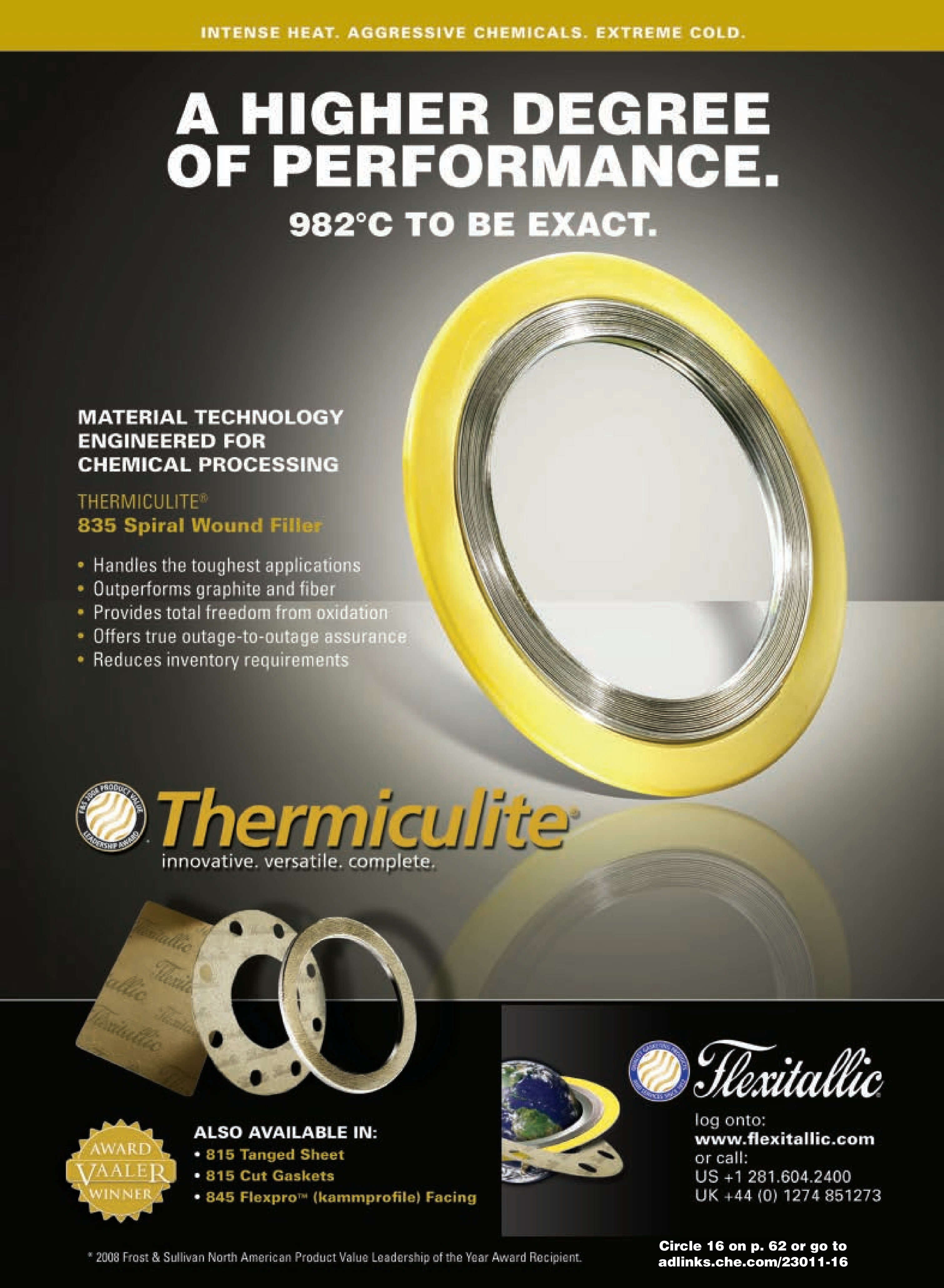
Microbia's fermentation process is carried out with the yeast *Yarrowia lipolytica*. Unlike most fermentation processes for carotenoid manufacture, this yeast achieves very high yields of the carotenoids, with a unique strain engineered for the production of each carotenoid. A series of optimized enzymatic steps facilitates efficient biosynthesis.

In addition to the technology inherent in its carotenoid commercial interests, Microbia is also collaborating with partners, such as Tate & Lyle Plc (London, U.K.), to develop bioprocesses for manufacturing larger-volume, commodity chemicals. ■

(*Continued from p. 14*)

certain pipelines. The rule also includes an increase in the design factor from 0.32 to 0.40, which applies to PA-11 pipe with standard dimensional ratio (SDR) in diameters 4 in. and smaller. Service tubing sizes may have lower SDRs.

The new rule gives operators of natural gas pipelines the option to use PA-11 pipe in certain pipeline systems. Arkema Inc. (Philadelphia, Pa.; www.arkema-inc.com), which petitioned the rule change back in October 2004 following extentensive field tests of its Rilsan PA11 pipes, says the amended rule will enable the oil and gas industry to "fully realize the cost-saving and ease of installation benefits of Rilsan P11." For the same cost benefits, Rilsan PA11 pipes offer all the advantages of conventional polyethylene pipes at pressures normally requiring steel, including coiled pipe that can be plowed or planted, joined by butt fusion and electrofusion, and squeezed off like conventional pipe, says the firm. ❏



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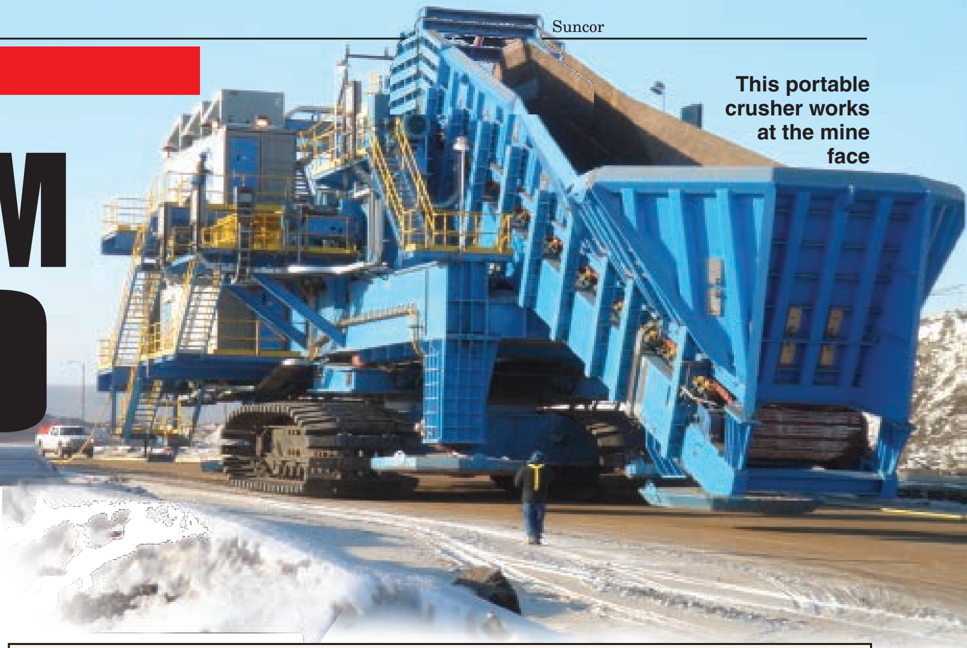
OIL FROM SAND

The oil sands industry is growing fast, and so is its impact on the environment



Suncor

This portable crusher works at the mine face

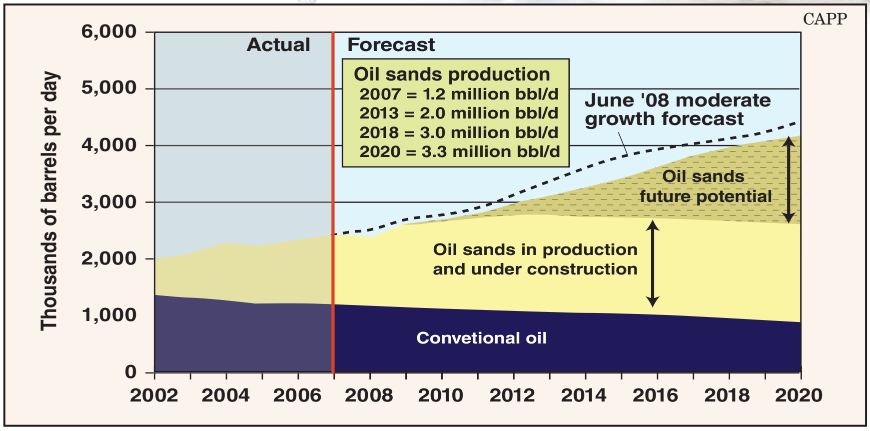


FIGURE 1. Despite its rapid growth, Western Canada's production of bitumen from oil sands will actually dip below last June's "moderate growth" (MG) forecast over the coming years. Conventional oil production will decline

In these hard economic times, people working in troubled businesses may well envy the situation of Alberta's oil sands industry. The Canadian Association of Petroleum Producers (CAPP, Calgary, Alberta; www.capp.ca) predicts that the production of synthetic crude from oil sands will reach 3.3-million bbl/d by 2020, up from 1.2-million bbl/d in 2007. Much of this oil will be sent to the U.S. via an expanding network of pipelines (*CE*, May 2008, p. 22).

As it happens, though, the industry has been impacted by the current business recession causing a number of companies to delay their expansion plans. For example, Suncor Energy (Calgary; www.suncor.com) announced a $20.6 billion* expansion program a year ago, with the goal of expanding production from 350,000 bbl/d to 550,000 bbl/d by 2012. More recently, the completion date has been pushed back to 2013 and the company has scaled back its capital spending plans for 2009 by more than one-third. Similarly, Fort Hills Energy L.P., a new venture, has deferred a final investment decision on mining operations and delayed indefinitely a decision to build an upgrader (delayed coker). Petro-Canada (Calgary; www.petro-canada.ca), the majority partner in Fort Hills, has reduced its capital and exploration expenditures to about $4 billion this year, down from about $6 billion in 2008. Petro-Canada's investment in oil sands in 2009 is expected to be about $985 million, down from about $1.4 billion in 2008.

*All dollars are Canadian (CAN$1 = US$0.82, January 13)

Alberta's recoverable reserves of oil sands total about 175-billion bbl, says Greg Stringham, CAPP's vice-president for oil sands and markets. Currently, about half the production is done by surface-mining the sand and its associated bitumen, then separating and upgrading the bitumen to obtain a synthetic crude (syncrude) for refining. However, only about 20% of the reserves are amenable to surface mining, so the trend is toward increased use of *in situ* processing to exploit deposits 200 ft or more below the surface.

Process technology

The main drivers for technology innovations in oil sands production are a desire to reduce costs and environmental impacts. Operating costs vary widely, but are currently in the range of US$30–35/bbl, says Stringham. Syncrude Canada Ltd. (Fort McMurray, Alta; www.syncrude.ca) reported operating costs, including purchased energy costs, of $24.64/bbl for 2007, down from $26.46/bbl in 2006.

In a surface-mining operation, oil sand is scooped up by huge shovels, trucked to a crusher, then slurried with warm water and piped to an extraction plant. There, hot water (40–50°C) is added, air and process aids are injected into the stream, and the mixture is fed to a conical primary separation vessel. Sand settles to the bottom of the vessel and the overflow is a froth that contains about 60% bitumen, 30% water and 10% clay.

Naphtha is typically mixed with the froth to lower the viscosity of the bitumen, making it easier to separate it from the water and clay by centrifuging or settling. Finally, the bitumen and naphtha are separated by distillation. The naphtha is recycled and the bitumen, whose specific gravity is about 10 API, is upgraded by delayed- or fluid-coking to obtain a synthetic crude of 25–30 API for refining.

The downside of these operations is that they use large volumes of water and have created huge tailings ponds that contain toxic residues. Air pollution is also a concern, and emissions of carbon dioxide are a major issue (see sidebar). In their defense, spokespersons for industry point out that they recycle at least 90% of the water they use, with zero discharge, and the net water use averages roughly 4 barrels per barrel of produced oil.

The popular process for *in situ* mining is steam-assisted gravity drainage (SAGD). A horizontal well is drilled into the oil formation, and a second, producer well is drilled parallel to it at a lower level. Steam is injected into the upper well to liberate the bitumen, which is pumped out from the producer well.

Benefits of *in situ* mining are that the produced bitumen is "clean", there are no tailings, and water use is much lower than those of operations based on surface mining. Petro-Canada says its net water use for SAGD (including 90% water recycling) is about 1/3 barrel of water per barrel of product.

On the other hand, energy use is high and there are air emissions from the steam boilers. Several new technologies are being developed and implemented to alleviate these problems and to cut costs (see below).

Companies whose operations start with mining are striving to improve efficiency throughout the process train. At the beginning of the train, Suncor has been using a mobile crusher at the mine face for more than a year. Built to Suncor's specifications by MMD (Summercotes, England), the tracked unit can process 5,000 metric tons per hour (m.t./h) and is linked to a mobile slurry unit, thus reducing the cost of truck haulage and reducing air emissions. Suncor expects to have two more mobile crushers operating within three years.

Syncrude has designed a compact slurrying unit for use with a mobile crusher at the mine face and field-tested a 4,000-m.t./h prototype, which is about half the size of a commercial unit. The company is now doing engineering design for a commercial system, says Alan Fair, manager of research and development. The equipment will be moved every few weeks by commercially available crawler transports. Fair notes that haulage trucks cost about \$5 million each, "so it's a costly way to move ore."

An improved froth treatment process, for separating bitumen from the froth after primary separation, has been developed by Shell Canada Ltd. (Calgary; www.shell.com). Naphtha is normally mixed with the froth to lower the viscosity of the bitumen and ease the separation, as noted earlier. Shell, in contrast, has for several years used paraffinic technology developed in cooperation with Natural Resources Canada's CanmetEnergy (Devon, Alta.; www.nrcan.gc.ca).

Shell has now developed an improved paraffinic process, called Shell Enhance, and plans to start up a commercial plant at its Muskeg River Mine in 2010–2011. The new process operates at above 60°C, versus 25–35°C for the earlier process. The advantages of paraffin over naphtha, according to Shell, are that the bitumen product has a lower solids and water content and there is partial deasphalting of the bitumen. Shell Enhance is an improvement over the earlier process in that it improves energy efficiency by 10%, uses 10% less water and requires less space.

Coking

In contrast with the situation in a conventional petroleum refinery, coking is an important unit operation in oil sands processing. "Most petroleum refiners use the coker as a garbage can to process the bottoms and heavy oil, but in our case most of our feed goes through a coker," says Alan Fair, manager of research and development for Syncrude. The company has three fluidized-bed cokers — two older ones with nameplate capacities of 107,000 bbl/d and a 95,000-bbl/d unit that started up in 2006. "These are the largest fluid cokers in the world," says Fair.

Syncrude has installed baffles in the reactor product-recovery section of one of the cokers to improve product fractionation. The company plans to make similar modifications to the other cokers during future scheduled shutdowns. The cost is about \$1 million for each project, but Syncrude says the potential savings could reach \$9 million/yr through longer run times and improved product quality. The baffle was developed by the company's R&D department, with help from ExxonMobil (Fairfax, Va.; www.exxonmobil.com), licensor of the fluid coking technology.

Syncrude is also investing \$1.6 billion to retrofit lime spray dryers on the two older cokers for sulfur emissions control. Scheduled for startup in 2010 or 2011, the project is expected to reduce emissions from the two units by about 60%, reducing the total sulfur emissions at the site to less than 100 m.t./d.

The newer coker uses an aqueous ammonia scrubbing process from

OIL SANDS AND THE ENVIRONMENT

Toward mid-year, Alberta Energy (Edmonton, Alta.; www.gov.ab.ca) the provincial government's energy department, will award three to five contracts for pilot projects for carbon capture and storage (CCS). Total funding is \$2 billion (Canadian) and the goal is to capture 5 m.t./yr of CO_2 and develop a pipeline network to transport the gas for use in enhanced oil recovery (EOR) or injection deep underground.

The CO_2 initiative is welcomed by Stephen Kaufman, chairman of ICO2N (Calgary), a group of some 20 industrial companies that studies CCS. In a recent report ICO2N outlined a scheme for a CCS system to reduce CO_2 emissions by 20 million m.t./yr, at an estimated cost of more than \$100/ton.

Last year was the first full year of an Alberta regulation that requires companies emitting more than 100,000 m.t./yr of CO_2 to reduce their emissions by 12%. Those that don't meet their targets may buy offsets or pay \$15 for each ton over the limit. The Alberta government was the first in North America to issue such a regulation.

Environmentalists complain that the regulation is based on intensity (for example, per barrel or kWh), rather than placing a cap on plant emissions. "The oil sands industry produces about 4% of Canada's greenhouse gas emissions and this is set to triple to 12% by 2020," says Simon Dyer, director for oil sands with the Pembina Institute (Calgary; Pembina.org), a sustainable energy think tank. He adds that the regulation does not encourage polluters to use CCS. "Paying \$15 a ton, when CCS may cost around \$100/ton, is a perverse incentive not to use CCS," he says.

Dyer notes that current oil sands operations cover about 600 km^2 of land in northeastern Alberta and have the highest environmental impact of any oil production in the world. As for land reclamation, he says that so far virtually no land has been certified as reclaimed, nor any tailings ponds, which comprise "about 130 km^2 of toxic liquids." ❑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Marsulex Inc. (Toronto; www.marsulex.com). The NH_3 reacts with SO_2 to form an ammonium-sulfite slurry, then air is bubbled through the slurry to obtain ammonium sulfate, which is sold to the fertilizer industry.

Syncrude chose this process because ammonia is generated as a byproduct in the hydrotreating plant, says Paul Ibbotson, a process engineer. However, trace compounds in the gas caused an odor, so the company has been buying NH_3 until it finds a way to deal with the offending compounds.

Suncor will install three trains of paired delayed cokers for its planned 200,000-bbl/d expansion. The project, dubbed Voyageur, will process bitumen from a combination of surface- and *in situ*-mined sources (Figure 2). The company has been using some SAGD for about five years, says a company spokesman, "but in the next 5–7 years we expect it to account for about 50% of our bitumen recovery."

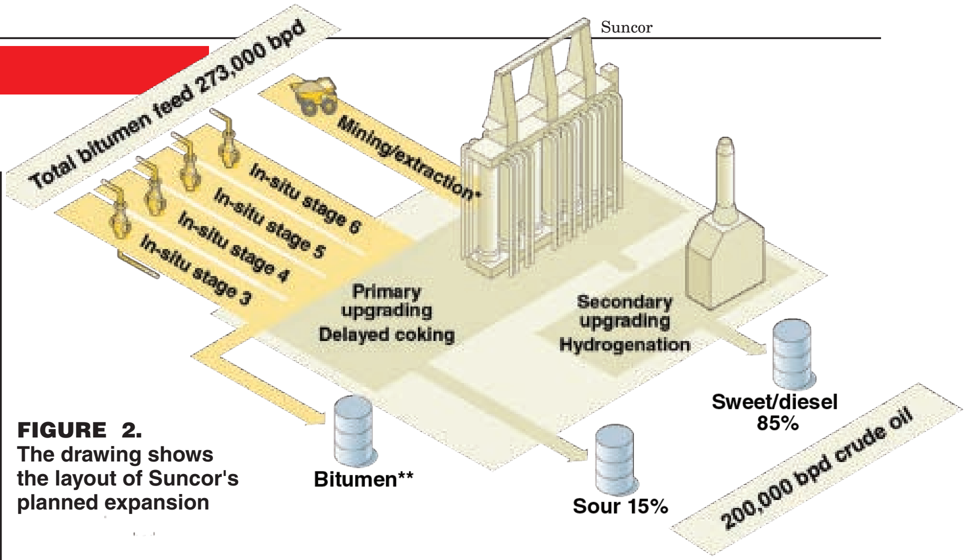

FIGURE 2. The drawing shows the layout of Suncor's planned expansion

Tailings treatment

Surface-mining operations produce tailings that are a mixture of water, clay, sand, residual bitumen and naphthenic acids. The problem is that the clay stays suspended, settling to a maximum of only 30–40% solids content after 3–5 yr, says Randy Mikula, team leader for the extraction and tailings group with Canmet.

Indeed, Suncor is only now reclaiming its first tailings pond after decades of operation. Suncor pioneered the use of consolidated tailings technology, developed in association with Canmet, in which tailings are consolidated by chemical treatment. In Suncor's case, gypsum (from SO_2 scrubbing) is added to the tailings to accelerate the release of water. Suncor's Pond 1 is now being infilled with sand, after which the company will contour the surface and plant vegetation.

A process in which CO_2 is injected into the tailings pipeline is being commercialized by Canadian Natural Resources Ltd. (CNRL, Calgary; www.cnrl.com). CNRL developed the process in collaboration with Canmet. The injected CO_2 forms carbonic acid, which changes the pH and coagulates the clay, thereby increasing the settling rate of the tailings, says Theo Paradis, lead operations engineer. CNRL is using the process to treat the tailings from its new 110,000-bbl/d oil sands plant, now starting up. Paradis expects it will permit settlement of the tailings within weeks, rather than years.

An improved process will be used in the project's second stage, when the plant will increase oil production to 232,000 bbl/d. The tailings volume will be reduced by thickeners and cyclones. Warm water will be recycled to the process from the thickener, and waste heat from the coker will be used to heat the process water, eliminating the use of natural gas. About 26 m.t./h of CO_2 will be obtained from the onsite H_2 plant. The deposited tailings may be trafficable "almost immediately," says Paradis.

In another process, developed by Syncrude in collaboration with Canmet, organic polymers are added to tailings, which are then centrifuged to separate the clay from the water. Syncrude has tested the process at a scale of 20 m.t./h and increased the solids content of the tailings from 17–20% to 55–60%. The separated water was returned to the bitumen-extraction process.

As an alternative to consolidating tailings, Syncrude has piloted a water capping method, in which lakes have been built in former mines, with soft tailings forming sedimentary bottoms. Syncrude says its research indicates that the lakes will, over time, support plant and wildlife.

In situ processes

The conventional *in situ* mining process is SAGD, as noted earlier, but this method uses large volumes of natural gas to raise steam, and there are air emissions from the steam boilers. A number of companies are working on new technologies that reduce or avoid these problems.

Petrobank Energy and Resources Ltd. (Calgary; www.petrobank.com) is piloting a process called THAI (Toe-to-Heel Air Injection). A horizontal producer well with a slotted liner is drilled at the base of the oil sands formation, which may be 20–30 m thick, then a vertical injector well is drilled to the end (toe) of the producer well. Steam is injected for 2-–3 months to raise the reservoir temperature to about 100°C. Finally, air is injected at 450–550 psi, initiating a combustion front that moves along the axis of the producer well, causing oil to flow into the well.

"The oil just rises to the surface by gas lift, without pumping," says Barry Noble, a management adviser with Petrobank. Asphaltenes remain in the sand to provide fuel, he says, so the produced bitumen has an API gravity "in the middle teens," versus eight for raw bitumen. Compared with SAGD, there are substantial savings in capital costs and water and energy, he adds, because steam is used only at the beginning of the cycle. Petrobank has piloted the process and plans to build a 10,000-bbl/d demonstration plant.

Shell is developing an *In situ* Upgrading Process (IUP) in which the oil is heated by electrical resistance heaters that are inserted in wells. The heat upgrades the bitumen into a lighter crude and gas that can be recovered, leaving coke in the ground. Shell has been field-testing IUP for several years, using 18 heaters and three producer wells. So far, more than 100,000 bbl of light oil has been produced at the site, but Shell says further work is necessary before the process can be commercialized. ■

Gerald Parkinson

TAKING THE PLUNGE

Chemical processors should begin looking into water reuse systems now, as experts suggest tightening water supplies will soon be a reality across the U.S.

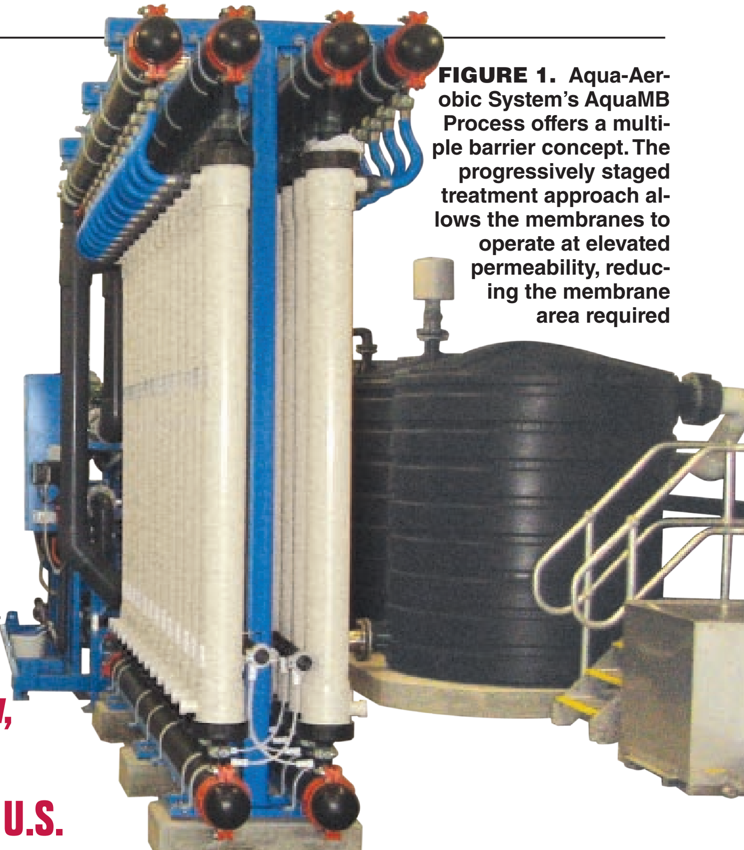

FIGURE 1. Aqua-Aerobic System's AquaMB Process offers a multiple barrier concept. The progressively staged treatment approach allows the membranes to operate at elevated permeability, reducing the membrane area required

Aqua-Aerobic Systems

Globally, water reuse and recycling are not uncommon — with parts of Australia, South Africa and the Middle East rather heartily embracing the practice. Even in Europe, it is estimated that 75 to 80% of water is reused. However, because fresh water is prevalent and plentiful in most parts of the U.S., few domestic chemical processors, or other industrial consumers of water, have yet to take the plunge when it comes to treating and reusing contaminated water supplies.

However, industry experts anticipate that this will soon change, sending the U.S. chemical process industries (CPI) on a quest to find the best and most economical method of treating and recycling wastewater from their own plants or from the municipalities that supply their water.

"With 36 states expected to experience moderate to extreme water shortages by the year 2013, the time has come for the U.S. to rethink its approach to the treatment, storage and reuse of water on a residential, industrial and municipal level," says Shane Keaney, president of Bord na Móna Environmental Products U.S. Inc. (Greensboro, N.C.).

According to the Palmer Hydrological Drought Index, at the end of 2007 38% of the U.S. was experiencing moderate to severe levels of drought. By 2013, the same index estimates at least 36 states will face water shortages.

As a result, the availability of municipal facilities to take on the water needs of the CPI and other large industrial users will start shrinking, causing the use of freshwater to become more costly, says Mark Boone, vice president of sales and marketing with HPD, a Veolia Water Solutions and Technologies company, (Chicago, Ill.).

As the availability of freshwater starts shrinking and plant sites start to grow, it will become more of a challenge to access a broad array of freshwater sources, reasons Chuck Martz, global marketing director for Dow Water Solutions (Midland, Mich.). "For this reason, getting to zero liquid discharge or using less scarce sources of water to reduce the freshwater footprint is certainly a growing trend," notes Martz.

As a matter of fact, conservation may soon be mandated in many areas, according to Boone, who says the permitting process for chemical processors and other industrial water users looking to expand or update facilities is becoming more stringent. "Almost any processor seeking a permit is being asked to examine the possibilities of water reuse and recycling as part of the permitting process. Already in some areas of the U.S. and around the world, the only way to get a permit for an expansion is to go to zero-liquid discharge," he says.

"In the western world, the value of water in dollars per gallon is not at the point where zero-liquid discharge or water recycling will necessarily provide a return on investment. However that doesn't mean that it won't be the case in the future because high-quality water is becoming more precious as its availability continues to dwindle," explains Boone.

Technology selection

With that in mind, now may be the time to start considering the risk of not having freshwater available and, based on that risk, considering the most promising technologies for recycling contaminated water. While there are several capable technologies currently available (see for example, *CE*, September 2008, pp. 44–50, and *CE*, October 2008, pp. 60–68), finding the one that is right for a given plant or application can be tricky because there is no single technology that works for every application.

When you look at reusing water, the form of treatment will vary depend-

Aquatech

FIGURE 2. Aquatech's HERO system is a reverse osmosis technology designed to purify difficult-to-treat feed waters. In a HERO system, RO membranes are operated in a high pH environment and hence, in a continuous cleaning mode, eliminating the potential foulants and resulting in improved overall performance

ing on what's being made in the facility, says Thomas Schultz, director of sales and marketing, petroleum and chemical industry with Siemens Water Technologies (Warrendale, Pa.). Another impact on technology choice is the stream that is being reused. "Most people think of wastewater recycling as taking all the wastewater at the back end of a facility, cleaning it up and trying to reuse it. Often that's the most difficult way to proceed," says Schultz. "A lot of times, it is easier, more feasible and more economical to isolate specific streams within a facility that are already relatively clean."

He says technology selection also depends on how you want to reuse the water. "Do you want to reuse water for fire prevention or non-agricultural irrigation, neither of which requires high-quality water? Or do you need boiler feedwater, which must be of higher quality than drinking water?" he asks. "It's really a matter of determining what each facility needs to do when trying to reuse the water and then matching up those needs with the different qualities or different types of wastewater generated within a facility and finding a technology that can handle the requirements at the lowest cost possible."

That said, initiating a wastewater management program within the facility is usually a good starting point. This step identifies water sources and characterizes the streams from those sources on a segregated basis. From there, processors need to look at where they can use the water within the facility to provide a better handle on where the water will come from, where it will be used and what can be done during the process in between to produce less contaminants in the water. "This is where most people start because it's the low-lying fruit and provides easy return on investment," says Boone.

Once that evaluation has taken place, it's time to move on to examining the resultant waste stream or streams to be treated and looking at the available technologies to see which one or ones will meet the needs of the plant.

Keep in mind that there is no single technology that works for all applications, says Mike Mowbray, marketing manager, U.S. Water Services (Cambridge, Minn.). "Each system must be designed based on the quality of the waste stream that is being recovered, the quality requirements of the water needed to be returned to the process and the operating needs of a particular facility."

He says there are mature technologies such as cold lime softening that may be employed or more modern, and very promising, membrane-related methods, such as membrane bioreactors, ultrafiltration, reverse osmosis and others to consider.

Membrane technologies

Currently a lot of work is being done with membranes. Membrane bioreactors (MBR), which involve biological treatment using microfilter or ultrafilter technology to remove biological contaminants from wastewater, are getting a lot of attention. This method is said to provide higher-quality treated effluent than conventional biological systems, and there are several variations on the technology.

For example, Siemens provides the MemPulse MBR system, which uses a mechanical device that supplies irregular pulses of air to the MBR module. This increases scouring effectiveness, decreases operational and maintenance costs and reduces energy consumption. The device works by introducing air and mixed liquor into the bottom of the membrane modules through an "airlift effect." The air bubbles blend with the mixed liquor and rise up into the membrane fiber, providing effective scouring to the membrane surface and refreshing the membrane surface to prevent solids concentration polarization.

The system can be used in a range of industrial wastewater treatment applications and can be retrofitted to existing plants wishing to replace conventional clarification processes with membrane separation.

Another wastewater recycling method is ultrafiltration, a pressure-driven membrane separation process that helps remove particulate matter from water or other aqueous solutions. Dow Water Solutions' UF membrane is made from high-grade polymeric PVDF material to form a hollow fiber membrane that is very durable and less prone to breakage. The hollow fiber has a dense layer, or skin, on both the inside and outside surfaces, forming a double-walled structure that contributes to its strength. In addition, its fouling resistance is improved by making the membrane surface more hydrophilic than the underlying PVDF polymer. With uniform pore size and outside-in-flow, Dow's UF membrane creates a barrier without sacrificing performance.

As an alternative to these methods, Aqua-Aerobic (Rockford, Ill.) offers a multiple barrier (MB) approach that incorporates progressive staged filtration, called the AquaMB Process. The multiple barrier concept main-

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tains the focus on contaminant removal in the biological reactor, without interference from the membrane operations. This progressively staged treatment approach allows the membranes to operate at elevated permeability, reducing the membrane area required. Depending on the membrane type selected (submerged or pressure) the membrane area required to process a given flow is as little as 20% of that required with a membrane bioreactor.

The multiple-barrier layout also provides the operator with the ability to discharge high-quality effluent directly from the sequencing batch reactor, cloth-media filtration system or from the membranes. The membranes can also be operated on an as-needed basis.

For difficult-to-treat water such as that coming from cooling tower blowdown, high silica well and surface waters, process wastewaters high in organics, mining wastewaters, produced water and other waste streams, reverse osmosis (RO) can be used following, or in some cases instead of, other membrane treatments.

Aquatech (Canonsburg, Pa.) offers a High Efficiency Reverse Osmosis, or HERO, System for such situations, saying it offers benefits beyond conventional RO processes. In a HERO system, RO membranes are operated in a high pH environment and in a continuous cleaning mode, eliminating potential foulants, and resulting in improved performance. The system provides higher water recovery, reducing the cost per gallon for pure water production and is not limited by Silt Density Index (SDI), which is a contributor to conventional RO fouling. Since SDI is not a limiting factor, up-stream systems such as microfiltration or ultrafiltration may not be necessary with this RO system.

Concentrated waste streams

While the water treatment technologies may differ, they have one thing in common — the creation of a concentrated waste stream. "There's a little thing that people tend to forget when they are looking into recycling of wastewater, and that is concentrated waste," warns Siemens'

Schultz. "What happens with these systems is that when you extract the clean water from the waste, you end up concentrating the waste. It may be a small amount of waste, but it's a higher strength because it's been concentrated and you now have to dispose of this waste."

This is typically where recycling process water gets expensive and becomes "bogged down," says Boone. "Pretreatment and membrane system are manageable costs and can provide an economic benefit even at today's water values. But because of the concentrated waste, water recyclers are forced to either deep well inject, discharge to a surface water body or thermally treat the concentrate.

On the bright side, however, Boone says there are advances to these technologies that may make dealing with the concentrated waste stream more feasible. "We are looking at getting greater performance and greater recovery out of membrane systems, which reduces the volume of concentrate being produced," he says. In addition, the application of advanced and more affordable evaporation and crystallization technology is becoming an option. "We are working on a variety of aspects to reduce the capital and operating costs of the final concentrate processing systems," notes Boone.

HeBei DaTang WangTang International HuaTan Electricity Co. Ltd.

FIGURE 3. Skids of Dow Ultrafiltration modules, such as these in the HeBei WangTang Power Plant in China, meet the challenges of high turbidity and fluctuating water temperature to produce acceptable feed water

Return on recycling investment

While there is still no or only a marginal payback for water recycling in most parts of the U.S., that will change as the technology continues to advance and be employed by more processors, according to the experts. Until then, processors can take baby steps toward water recycling that will provide a return on investment, says U.S. Water Services' Mowbray.

If water is heated, minimizing discharge or reusing and recovering the heat usually provides a surprisingly fast ROI. "While more sophisticated systems can be expensive, as fresh water becomes more valuable and sewer charges increase, the ROI on these projects gets much better," notes Mowbray. "And if discharge permits can only be met through water reuse, then the ROI is pretty easy to meet."■

Joy LePree

Selecting A Conveyor

Characteristics of flexible screw, aero-mechanical, vacuum and pneumatic conveyors are discussed here

Michel Podevyn, Spiroflow Systems, Inc.

FIGURE 1. Flexible screw conveyors are the simplest and least expensive solution and can be curved to some extent, depending on the diameter

Conveyor selection is always defined by the larger project that it is meant to serve. First, there is a broad range of performance factors that must be met. Meanwhile, health, safety and environmental considerations usually outweigh the costs involved. After that, it comes down to the usual commercial considerations of price and delivery.

What follows are the main parameters, benefits and disadvantages of four different types of conveyors, namely flexible screw, aero-mechanical, vacuum and pneumatic.

Meanwhile, the task of working with vendors — both after and often during the choice in conveyor type has been made — is covered in the box on p. 28.

Flexible screw conveyors

Flexible screw conveyors (Figure 1) are often the simplest and lowest cost solution for transferring a variety of materials from Point A to Point B at rates of up to 40 ton/h over distances of up to 65 ft. If greater conveying distances are required, multiple systems can be linked together.

Flexible screw conveyors consist of a special heat-treated and tempered carbon or stainless-steel spiral that rotates within an ultra-high-molecular-weight polyethylene (UHMWPE), food-grade tube. This type of conveyor is well suited for powdered, granular or flaked materials with a bulk density up to 150 lb/ft^3.

The term flexible means that this type of conveyor can be curved to some extent, depending on its diameter. This provides the user with the flexibility to route the conveyor around obstacles anywhere between the inlet and outlet. Normally, using only one continuous curve is recommended.

For most applications, the spiral itself has a round cross section, but a flat or profiled version can also be used for fine, cohesive or easily smeared materials.

Flexible screw conveyors are designed to operate when full of material; running empty will lead to excessive noise and wear. Having a head of material in the feed hopper is desirable since it helps with the elevation of material upon startup of the conveyor.

The main benefit of the flexible screw conveyor is its inherent simplicity, which translates into low initial cost, quick installation and low maintenance. For the needs of pharmaceutical, food and dairy applications, specific models are available that can be safely stripped down in minutes for thorough cleaning.

Wear is only a problem with abrasive products; operating lifetime with other materials is almost indefinite. Tubes and spirals can be easily replaced. One of the latest developments is abrasion-resistant rubber tubes for such applications as aggregates, sand, cement and glass cullet.

Since this type of conveyor should always operate while full, it is not recommended for transferring preweighed batches to a receiver. Flexible screw conveyors are best used to deliver product from storage or a bag tip station to a weigh hopper or a vessel with a high level switch. For example, it is ideal for maintaining a constant head of material in packing machine hoppers by gently filling to the high level control rather than dumping pulsed batches. Because the in-flight product is constant, flexible spiral conveyors will give very accurate, highly repeatable batches if controlled by a simple time switch.

Although flexible spiral conveyors need to run full of product, they can be emptied at the end of a batch operation or at the end of a shift by removing an end bung and running the conveyor in reverse at a reduced speed if necessary.

Aero-mechanical conveyors

The second type of conveyor, the aero-mechanical conveyor (AMC; Figure 2), is ideal for total transfer of products at distances from 10 to 85 ft at rates of up to 120 ton/h.

An alternative and more descriptive name of the AMC is a rope and disk conveyor. This is because the AMC consists of several evenly spaced polyurethane disks attached to a wire rope. The rope and disks travel in a continuous loop fashion at a consistently high speed within parallel steel tubes. At each end, there are enclosed housings. Within these housings, the rope assembly runs from one tube to the other around specially designed sprockets. One of these sprockets drives the rope and disks while the other sprocket provides tension to the rope. The high speed of the disks produces an air stream that fluidizes and entrains the product in airflow until it is centrifugally ejected at the outlet.

INFORMATION TO PREPARE FOR POTENTIAL VENDORS

As part of the selection process, an engineer needs to do his or her homework and provide the supplier with answers to certain questions. At a minimum, the engineer should be prepared to provide answers to the following 21 questions for all of the bulk materials to be conveyed:

1. What materials need to be conveyed?
2. What is the bulk density?
3. What is the condition of the product or material in terms of such criteria as moisture content, average particle size and temperature?
4. Is the product likely to change in any way in the future?
5. From what is the product being conveyed (for example, from a silo, bulk bag, or bag tip station)?
6. To what is the product being conveyed (such as a mixer, sifter, mill or reactor)?
7. If it's a reactor of any type, is there any steam, gas or solvent given off that might enter the conveyor?
8. What is the horizontal conveying distance?
9. What is the vertical height to which the product has to be conveyed?
10. What is the route of the conveyor (such as inside, outside or number of bends required)?
11. What is the conveying rate in pounds per hour or the batch size over a given time?
12. Will a pre-weighed batch be conveyed, or will the conveyor be transferring material to a receiver of a given size, on load cells; or is it a continuous process?
13. How often / for how long will the conveyor operate each day?
14. Is it important to deliver the material to the receiver in a homogenous manner, such as when flakes are added to a liquid to make a lump-free paste?
15. If the product is a mixture, is it essential that the integrity of the mix be maintained?
16. Is the material fragile and how important is it to minimize damage during conveying?
17. What accessories are required (such as a bag tip station, bulk bag discharger or receiver hopper)?
18. Will the conveyor operate in a dusty or otherwise hazardous area (for instance, will NEMA-rated explosion-proof motors and other such equipment be required)?
19. Is the conveyor manufacturer also supplying the control panel, level sensors and other accessories?
20. Will the conveyor be readily accessible for maintenance purposes?
21. How long is the conveyor expected to run between services?

Beside the questions above, a supplier will most likely also require additional information. What kind of information depends on the type of conveyor being considered and the supplier itself. ❑

This method of conveying facilitates capacities up to 120 ton/h with low energy requirements, minimal product degradation and virtually no separation of mixtures.

AMCs effectively operate as mechanical vacuum conveyors and should not be confused with drag-link type conveyors. Drag-link conveyors are slow-moving, heavy duty devices in which cast iron disks are often linked with rods or chains and where the product is scraped along inside the tube.

Over the years, the AMC has proven to be a cost efficient method of conveying materials, dust-free and without the need for filtration. The AMC offers total batch transfer, contaminant free delivery and operation at any angle (including vertical) without any loss of capacity. For easy cleaning, AMCs can also be supplied with access panels.

Besides straight-line operation, AMCs are available in a multitude of "round the corner" configurations. Other than free flowing powders, such as acrylics, flour and carbon black, AMCs can also convey difficult materials, such as titanium dioxide. They also do not have any problem conveying granules, flakes or chips.

A major benefit of this type of conveyor is that degradation of the material is almost negligible. This is because an AMC creates a moving current of air in which the bulk solid is carried similar to the mechanism of a vacuum or pneumatic system. However, unlike vacuum or pneumatic systems, the AMC has a very important advantage in that it does not need a cyclone or filter to separate the product from the air. This not only saves in capital cost but also reduces maintenance and eliminates environmental issues since the air carrying the material is recycled and not released at the outlet. The material is separated from the air that carries it, and the unloaded air current is directed down into the return section of the tube where it is retained in the tube circuit.

An AMC should always be started empty and fed at a controlled rate. With free-flowing products, a simple slide gate may be all that is required in terms of additional equipment. In other cases, a controlled feed device, such as a rotary valve or flexible screw conveyor, should be used.

One disadvantage of an AMC is that maintenance can range from moderate to high. The rope tension needs to be adjusted regularly during the all-important startup period and then checked periodically. Rope life depends upon the length of the conveyor, the number of starts and stops, solids loading and whether routine inspection and tensioning is properly performed.

Despite these drawbacks, properly maintained rope and disk assemblies on arduous duties have been known to last 14 years and longer.

The effort, worry and cost of this regular maintenance can be avoided by selecting an AMC with an integral automatic rope-tension monitoring and adjustment system.

Vacuum conveyors

The third conveyor type, vacuum conveyors (Figure 3), is the obvious choice where products need to be conveyed over longer distances and torturous routes. Vacuum conveying is usually restricted to throughputs of around 10 ton/h at distances over 330 ft.

A vacuum conveyor uses the negative air pressure to convey materials through an enclosed pipeline. It provides a solution for users requiring a system that is easy to route, has few moving parts, is dust tight in operation and empties a product leaving minimum residue. Since the air is sucked-in, vacuum conveyors are the preferred choice for toxic or otherwise hazardous materials in the event of accidental damage to the conveying tubes because the escape of product to the atmosphere is minimized.

Either an exhauster or a side-channel, high-efficiency fan located at the receiving end of the system, provides

FIGURE 2. This aero-mechanical conveyor (AMC) operates high up into the roof area. In this situation, rope tension maintenance could be more difficult without the use of scaffolding or a mobile access platform

FIGURE 3. The premise for vacuum conveying is simplicity in operation, inherent reliability and hygienic transfer of material. The basic principle of this type of system is to convey the product from a feed or supply source into a delivery point suspended in a relatively uniform system

FIGURE 4. In complying with pharmaceutical and food standards, pneumatic conveyors are easy to clean with minimal product degradation

the motive force. For low capacity conveying air-powered, venturi systems are ideal. Venturi systems offer low capital cost and are not as expensive to operate as many people have been led to believe.

Vacuum systems are normally the only conveying choice for customers that want to withdraw material out of bags or other open top containers such as kegs and drums. Vacuum systems are also ideal for applications with multiple inlets.

Reverse-jet, self-cleaning filters clean the conveying air and return the air to the atmosphere after use. This-type of filter reduces maintenance and minimizes product loss.

Pneumatic conveyors

Pneumatic conveyors (Figure 4) are probably the most versatile of all conveying systems, with the main negative aspect being high cost. There is virtually no limitation on capacity, product type, distance or routing. Lean phase systems (where the ratio of product to air is low) can move mountains of product. Dense phase or plug flow systems move "slugs" of product at lower speeds with minimal degradation.

Positive-pressure, pneumatic conveying is generally used to convey materials from a single source to one or multiple destinations. Pneumatic conveying systems are normally the luxury of big league applications, such as the rapid discharging of road and rail tankers into silos and the transfer of product from silos to large-scale production processes. Capacities of up to 100 ton/h are not unusual.

The two main disadvantages for pneumatic conveyors are the relatively high initial installation cost and the amount of filtration required. As with vacuum conveyors, self-cleaning reverse-jet filters are a big help in reducing maintenance. Maintenance is required to make sure these systems are free of leaks to ensure optimum efficiency and, above all, to avoid the associated health and environmental issues that are associated with leaks.

Other types of conveyors

Beside these four types of conveyors, there are several additional types available. These include the following:

- ***Rigid screw conveyors:*** Beware of the seals and bearings, which come into contact with the bulk solid material being conveyed
- ***Bucket elevators:*** This type of conveyor is ideal for the most delicate products but generally not for those that are dusty
- ***Flat belt conveyors:*** This type of conveyor is mainly used in quarries and mines
- ***Vibratory feeders:*** Vibratory feeders are ideal if only very short conveying distances are required
- ***Air slides:*** Air slides are fine for dense materials that only require downhill conveying

In some applications, a mix of different conveyor types is appropriate. For example, short "easy to clean" flexible screw conveyors are often used to provide a long distance, AMC with a consistent in-feed of material. ■

Edited by Rebekkah Marshall

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Michel Podevyn is president and CEO of Spiroflow Systems, Inc. (2806 Gray Fox Road, Monroe, NC 28110; Phone: 704-291-9595, Fax: 704-291-9594; Email: info@spiroflowsystems.com; Website: www.spiroflowsystems.com). Of Belgian origin, Podevyn spent much of his life in the U.K. where he was instrumental in the development of the Flexible Screw Conveyor. Originally targeted at applications in the plastics industry, the flexible screw conveyor is now universally used across the chemical process industries. With this development, Podevyn established Spiroflow Systems Ltd. in Lancashire, U.K. In the 1980s, he formed Spiroflow Systems, Inc. on back of the former Orthos Inc. in Monroe, N.C. This acquisition took Spiroflow into the aero-mechanical conveyor market. Over 20 years ago, Podevyn also anticipated the appeal of the now ubiquitous Bulk Bag and, as a result, developed a range of bulk bag filling and bulk bag discharging units, most of which are either fed or evacuated by one of the company's conveyors. Podevyn is also chairman of the Spiroflow Group, which has a similar manufacturing operation in the U.K. to serve the European market.

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Kate Torzewski

Pipe Sizing

FRICTION FACTOR

Fluid flowing through pipes experiences resistance due to viscosity, turbulence and roughness of the pipe surface. The Darcy-Weisbach Equation (1) is commonly used for the analysis of steady-state, Newtonian-fluid flow inside pipes. It summarizes the relations between frictional head loss, fluid properties, pipe geometry and discharge.

$$h_f = \frac{\Delta P}{\rho g} = \frac{8fLQ^2}{\pi^2 g D^5} \qquad (1)$$

For laminar flow (Re < 2,100), the friction factor is a function of Reynolds number only.

$$f = {}^{64}\!/_{\mathrm{Re}} \qquad (2)$$

In turbulent flow (Re > 4,000), f depends upon Reynolds number and pipe roughness.

Hydraulically smooth pipes. In this case, the friction factor is solely a function of *Re*. For the determination of friction factor, Von Kármán and Prandtl [2] developed Equation (3).

$$\frac{1}{\sqrt{f}} = 2.0\log\left(\mathrm{Re}\sqrt{f}\right) - 0.8 \qquad (3)$$

This correlation must be solved by iterative procedures, but simpler correlations given by Colebrook [3] and Blasius [4] are written as Equations (4) and (5), respectively.

$$\frac{1}{\sqrt{f}} = 1.8\log\left(\frac{\mathrm{Re}}{7}\right) \qquad (4)$$

$$f = 0.3164\,\mathrm{Re}^{-0.25} \qquad (5)$$

Commercial pipe. In this case, f is governed by both Re and relative roughness, expressed as ε/D. The Colebrook-White's Equation (6) is used to calculate f [3].

$$\frac{1}{\sqrt{f}} = -2\log\left[\frac{2.51}{\mathrm{Re}\sqrt{f}} + \frac{\varepsilon/D}{3.707}\right] \qquad (6)$$

As this equation requires trial-and-error solution, Altshul [5] has developed Equation (7), a computationally simpler choice.

$$f = 0.11\left(\frac{\varepsilon}{D} + \frac{68}{\mathrm{Re}}\right)^{0.25} \qquad (7)$$

PRESSURE DROP

To determine pressure drop, discharge and diameter must be known.

Hydraulically smooth pipes. Using Equation (1) and the friction factor correlation for smooth pipe, Equation (8) is found.

$$\Delta P = \left[\frac{Q^2\rho L}{D^5}\right] \cdot \frac{0.25}{\left\{\log\left(\mathrm{Re}/7\right)\right\}^2} \qquad (8)$$

Commercial pipes. Using Equation (1) and the friction factor correlation for smooth pipe, Equation (9) is found.

$$\Delta P = \frac{0.88}{\pi^2} \cdot \frac{\rho L Q^2}{D^5} \cdot \left[\frac{\varepsilon}{D} + \frac{17\,\pi\mu D}{Q\rho}\right]^{0.25} \qquad (9)$$

DISCHARGE

To determine discharge, pressure drop and diameter must be known.

Hydraulically smooth pipes. Equations (1) and (3) allow us to find an expression for the discharge of a smooth pipe.

$$Q = \frac{\pi}{\sqrt{8}}\left[\frac{D^5\Delta P}{\rho L}\right]^{0.5} \log\left[0.3171X\right] \qquad (10)$$

$$X = \frac{D^3\rho}{\mu^2} \cdot \frac{\Delta P}{L} \qquad (11)$$

Commercial pipes. Equations (1) and (6) allow us to find an expression for the discharge of a commercial pipe.

$$Q = -\frac{\pi}{\sqrt{2}}\left[\frac{D^5\Delta P}{\rho L}\right]^{0.5} \times \log\left[\frac{1.7748}{\sqrt{X}} + \frac{\varepsilon/D}{3.707}\right] \qquad (12)$$

PIPE DIAMETER

Rearranging Equation (1) to yield an expression for pipe diameter gives Equation (13).

$$D = \left[\frac{8\rho Q^2 L}{\pi^2 \Delta P}\right]^{0.2} f^{0.2} \qquad (13)$$

Smooth pipes. Substituting Equation (5) for f yields a correlation for pipe diameter.

$$X = \frac{D^3\rho}{\mu^2} \cdot \frac{\Delta P}{L} \qquad (14)$$

Commercial pipes. Determining the diameter of a rough pipe requires the use of Gu, the dynamic roughness.

$$\mathrm{Gu} = \mathrm{Re}\left({}^{\varepsilon}\!/_{D}\right) \qquad (15)$$

Manipulating Equation (7) to reflect Gu and substituting into the expression for pipe diameter gives Equation (17), commercial pipe diameter. Several design parameters can be condensed into a constant, named λ.

$$\lambda = Q^7\left(\frac{L}{\Delta P}\right)^4 \rho^3 \mu \qquad (16)$$

$$D = \left[\frac{0.15}{\pi^7}\lambda\right]^{1/19}\left[\mathrm{Gu}+68\right]^{1/19} \qquad (17)$$

The range of Gu is: 0 < Gu < 10^6, based on the known ranges of Re and ε/D for all pipe and flow conditions. Substituting these two extreme values of Gu into Equation (15) gives the following extreme cases, which a pipe diameter must fall between.

Case 1: Extremely smooth pipe. Gu = 0.

$$D_S = \left[\frac{0.15\lambda}{\pi^7}\right] \times 1.24867 = 0.74118\lambda^{1/19} \qquad (18)$$

Case 2: Extremely rough pipe. Gu = 10^6

$$D_R = \left[\frac{0.15\lambda}{\pi^7}\right] \times 2.06915 = 1.2882\lambda^{1/19} \qquad (19)$$

Here, we see that even for very rough pipe (ε/D = 0.01, Re = 10^8), the diameter estimate will be only about five thirds of that for smooth pipe.

NOMENCLATURE

D	Diameter of pipe, m
D_R	Diameter of very rough pipe, m
D_S	Diameter of very smooth pipe, m
D_1	Diameter of standard commercially available pipe, m
f	Darcy friction factor, dimensionless
g	Gravitational acceleration, m/s^2
Gu	Dynamic roughness, dimensionless
h_f	Frictional head loss, m
L	Length of pipe, m
Q	Volumetric flowrate, m^3/s
ΔP	Pressure drop, N/m^2
Re	Reynolds number, dimensionless, Re = $4Q\rho/\pi\mu D$
X	Dimensionless parameter (Eq. [11])
ϵ	Pipe roughness, m
λ	Dimensionless parameter (Eq. [16])
μ	Viscosity, N-s/m^2
ρ	Density, kg/m^3
ψ	Diameter multiplier, dimensionless

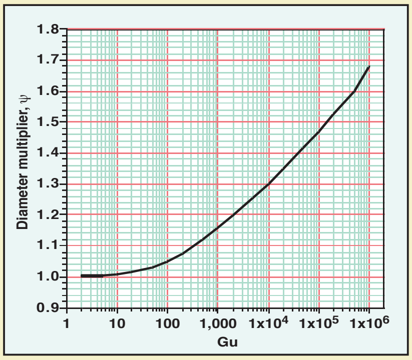

Figure 1 is a plot with Gu as abscissa and Ψ as ordinate. It has the expected limit at Gu = 0, at Ψ = 1. First, estimate a pipe diameter assuming smooth pipe. Using this diameter, calculate Gu from Equation (15). Then, from Figure 1, get the value of Ψ and multiply it by the diameter to get actual diameter needed for the commercial pipe.

GRAPHICAL SIZING METHOD

To avoid lengthy calculations, a graphical method can be used to approximate pipe diameter. Dividing Equation (17) by Equation (18), we get the diameter multiplier, Ψ.

$$\psi = 0.8\left[\mathrm{Gu}+68\right]^{1/19} \qquad (20)$$

A graphical method using Ψ can help to quickly estimate the degree of roughness the chosen pipe can withstand.

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People

WHO'S WHO

O'Keefe

Newton

Sanderlin

Torrence

Wallace

Stephen Weinberg joins **Audubon Engineering Solutions** (Houston, Tex.) as director of process technology.

Haws Corp. (Sparks, Nev.) names *William O'Keefe* corporate marketing manager.

Honeywell Process Solutions (Phoenix, Ariz.) appoints *Normal Gilsdorf* president.

Bill St. Thomas becomes sales manager of North America of **Ipsen, Inc.** (Rockford, Ill.)

Microbia Precision Engineering, Inc. (Lexington, Mass.) elects *Gaye Bok* senior director, commercial development, and elects *Sam Zeller* senior director, regulatory affairs.

Bob Newton joins **MIOX Corp.** (Albuquerque, N.M.) as vice-president, industrial markets.

Bryan Sanderlin is appointed president of **OSECO** (Broken Arrow, Okla.).

PAS Inc. (Houston, Tex.) elects *Chris Lyden* president.

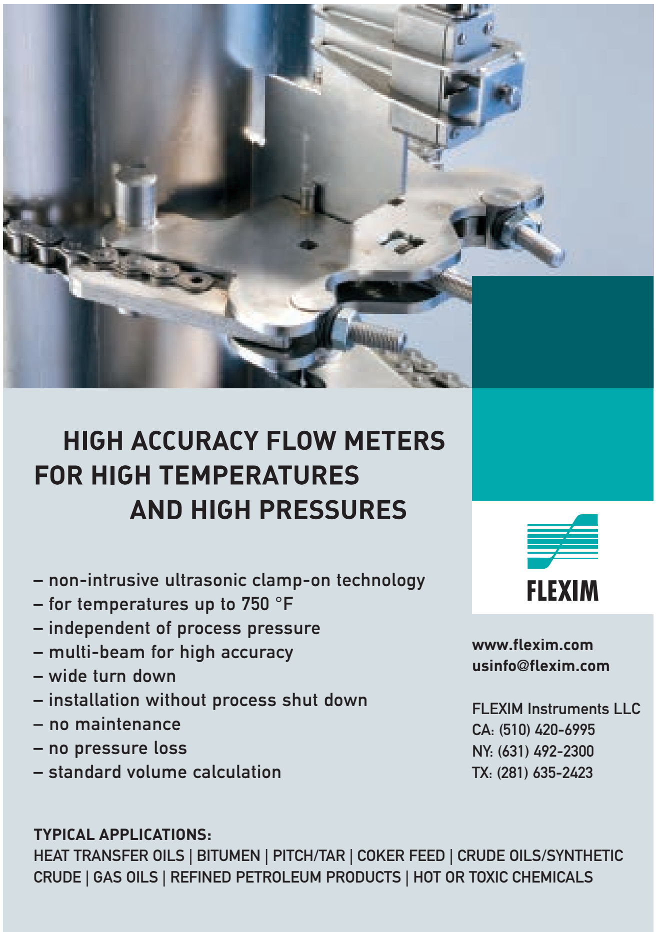
David Torrence is named vice-president and general manager of **Plastomer Technologies** (Houston, Tex.).

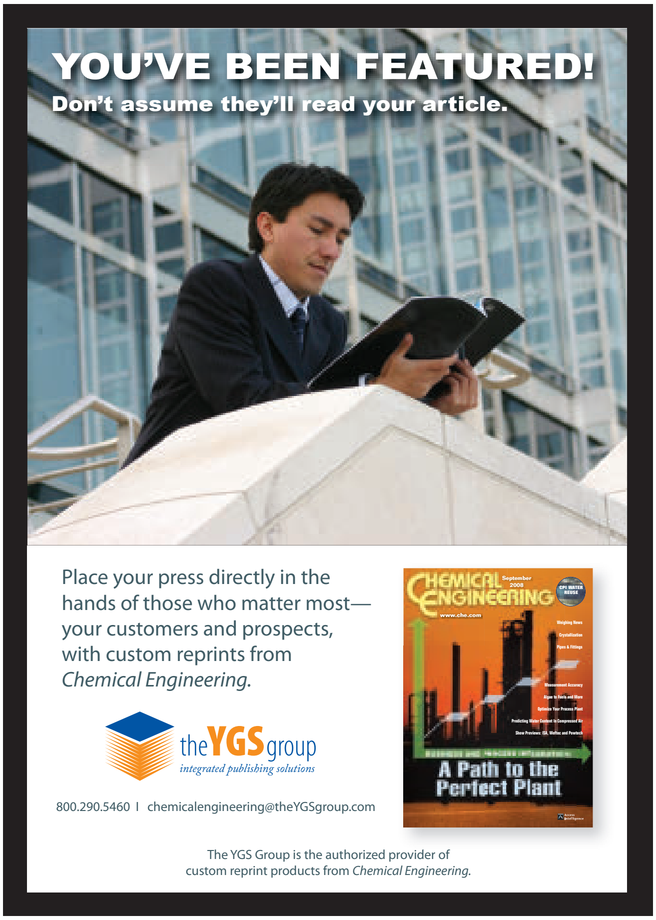
PPG Industries (Pittsburgh, Pa.) appoints *Charles F. Kahle II* chief technology officer.

Klaus Fuchs is appointed president and CEO of **Siltronic AG** (Munich, Germany).

Swagelok (Solon, Ohio) names *Deric Wallace* regional director, Europe. ■

Kate Torzewski





Swagelok

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Conference & Exhibition

The world's largest pharmaceutical conference and exhibition, Interphex, will be held at the Jacob K. Javits Convention Center in New York from March 17–19, 2009.

On the show floor, attendees will find equipment and solutions for drug manufacturing, from process development to market delivery. Interphex has organized the exhibitor list of nearly 800 companies into four major segments: Facilities, Outsourcing & Contract Services, Information Technology, and Manufacturing/Processing.

For more information, visit the show website at www.interphex.com. Here is a sampling of the technology that will be found at the exhibition.

This clean hose withstands extreme temperatures

The Coreflex Series U-COR smooth-bore hose (photo) is designed to maximize hoop strength, which helps reduce kinking while keeping the hose flexible. Coupled with sanitary end connections, Coreflex hose promotes increased drainability and flowrates. Swagelok Coreflex Series U-COR hose has insulation from internal system fluid temperature extremes, making it particularly useful for steam and other high-temperature applications. Features of the U-COR hose include a smooth-bore Fluoropolymer core, reinforced with a silicone layer bonded to the core, a 300 Series stainless-steel overbraid, and a smooth, noncontaminating silicone cover for no braid fray. Booth 2145 — *Swagelok, Solon, Ohio*

Booth 2145

www.swagelok.com

These discs allows 95% of the rated burst pressure

The Ultrx HP and Star X HP reverse acting discs (photo) achieve and control burst pressures at close tolerances. Their design allows pressurization up to 95% of the rated (marked) burst pressure under normal operating conditions for ratings above 40 psig. In this case, a standard burst tolerance of ±5% applies to the rated burst pressure. For rated burst pressures below 40 psig, the recommended operating pressure is 95% of the value of the rated burst pressure minus the burst tolerance (2 psig). The Ultrx HP excels in all-liquid systems as well as gaseous or partial gas/liquid systems. The Star X HP is designed to provide protection at burst pressures as low as 13 psig. Booth 1772 — *Continental Disc Corp., Liberty, Mo.*

www.contdisc.com

Find clean hoses and labeling systems from this company

AdvantaFlex biopharmaceutical-grade tubing (photo) is designed for media and viral filling and for sampling applications. AdvantaFlex provides excellent peristaltic-pump life, can be aseptically sealed in seconds, and welds directly to biobag containers, thus eliminating the need for silicone tubing grafts. Other products available from the company include silicone manifolds and molded components, fluoropolymer hose, silicone tubing and reinforced hose, AdvantaLabel hose-identification solutions and RFID tags to uniquely identify individual process components and hose assemblies. GammaTag RFID tags may be attached to single-use products, healthcare equipment and medical devices that require gamma sterilization before use. Booth 1555 — *AdvantaPure, Southampton, Pa.*

www.advantapure.com

Lab centrifuge with interchangeable bowl feature

This lab-scale separator is ideal for research and development purposes. The new SC 5 unit allows the operator to switch between three different bowl sizes. This enables the separator to process varying batch sizes from 20 to 400 L. Available as a package unit, the SC 5 can be ordered with all components pre-installed on a stainless-steel frame, including the centrifuge, control cabinet, fittings, instruments, pipework and wiring. To accommodate a wide range of process settings, bowl speed can be adjusted between 8,000 and 12,000 rpm. The SC 5 unit also

Note: For more information, circle the 3-digit number on p. 62, or use the website designation.

features a nozzle design that ensures clean-in-place (CIP) cleaning and a low-maintenance flat belt drive. Booth 1779 — *GEA Westfalia Separator, Northvale, N.J.*
www.wsus.com

Test the flow properties of powders in small sample sizes
As part of its position in characterizing powder flow properties and segregation tendencies, this firm has jointly developed with Pfizer material sparing segregation testers. These testers allow the use of smaller starting samples of blended powders, more accurate and repeatable test sequences, as well as contained recovery of typical unit dose sample sizes. In conjunction with other available testers and analytical methods, the underlying relationships between powder flow sequences and segregation behaviors can be determined and used to provide practical improvements to powder handling processes. Booth 1172 — *Jenike & Johanson, Tyngsboro, Mass.*
www.jenike.com

Use this dryer for small-scale production or trials
The Helical Dryer Model HD 40 (photo) is the latest development in the Krauss-Maffei dryer equipment product line. The unit is fully mobile, and provided with a PLC-based control panel including wireless data logging for operation in hazardous material areas. With a batch working capacity of 40 L, the unit can be used as a small-production dryer or for test trials for scaleup to production size batch mixer/dryers. Key features include a heatable shaft-mixing assembly, bottom discharge, only one mechanical seal, easy access for inspection and full cleanablility with CIP spray devices. Booth 3105 — *KMPT USA, Inc., Florence, Ky.*
www.kmpt.com

KMPT USA


Powder-testing ensures powder and process compatibility
The FT4 powder tester delivers the insight into powder behavior that is needed to understand powders, achieve compatibility between powder and plant and enable process optimization. The FT4 performs a range of methodologies, measuring shear, bulk and dynamic properties in a short time, using relatively small amounts of material.


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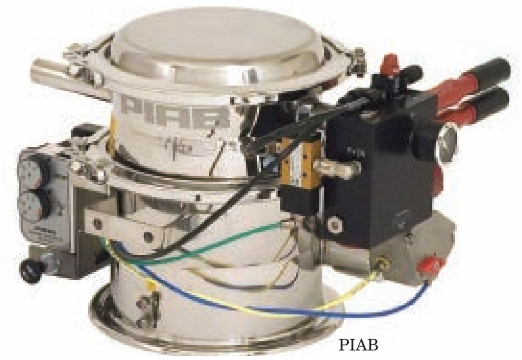
In addition, it is possible to define, in terms of easily measurable parameters, the characteristics of materials that will be optimal for a given piece of plant — a hopper or a tablet press, for example. Developing formulations that meet this specification ensures compatibility between the plant and powder, thereby building quality into the manufacturing process from the outset. Booth 1269 — *Freeman Technology, Welland, U.K.*
www.freemantech.co.uk

This energy-efficient vacuum conveyor works in limited spaces
This compact yet powerful new conveying solution, the C2100-64 vacuum conveyor, quietly and hygienically transports powder and bulk materials in limited spaces. The C2100-64 conveyor (photo) features COAX multistage ejector technology, consuming less air and energy than any other compressed-air-driven conveyor currently available, according to the firm. The design of the conveyor improves the vacuum-assisted flow by 25% without affecting energy consumption. The C2100-64 is able to transport up to 1.0–1.5 ton/h. This stainless-steel conveyor operates at feed pressures between 58 and 87 psi and at working temperatures between 0 and 140°F. Booth 2922 — *PIAB, Inc. Hingham, Mass.*
www.piab.com

Perform automatic particle sizing in wet processes
The flexible design of the Insitec LPS wet-process, particle-size analyzer enables it to be customized for specific applications in the pharmaceutical industry. Incorporating a sampler, pre-diluter, cascade diluter and measurement cell, the Insitec LPS is a fully automated system that measures particles from 0.1 to 1000 microns in almost any wet stream. Each component is tailored to the individual application in close consultation with the customer. Insitec LPS is supplied with the this firm's Link software package, which simplifies operation and facilitates integration with existing control platforms. Operating 24/7, it requires little manual intervention and generates particle size data at the frequency needed for realtime process control. An Intrinsically Safe (IS) version is also available. Booth 1038 — *Malvern Instruments, Malvern, U.K.*
www.malvern.com ■

Kate Torzewski


PIAB

FEBRUARY

New Products


Milton Roy Europe


Rechner Industrie-Elektronik


Hans Turck


Parker Hannifin

This compact I/O block module handles up to 16 signals

This new series of compact I/O modules (photo) uses technology based on the reliable BL67 modular I/O system, and includes different BL67 electronic components and a programmable gateway within a single epoxy-sealed housing that is resistant to dirt and shock. Up to 16 digital or analog signals on one single I/O block module provide increased application compatibility and enable the user to move towards a consistently decentralized process. The IP67 stations will be available in three housing sizes and six different I/O profiles for Profibus-DP and DeviceNet. The BL compact series will soon also support all established fieldbus protocols as well as Industrial Ethernet and IO-Link. — *Hans Turck GmbH & Co. KG, Muelheim an der Ruhr, Germany*
www.turck.com

Level control, even for sticky materials

Originally designed to cope with the problems associated with adhesive products, the 26 Series capacitive sensors (photo) have been found to have "excellent characteristics" for even general use in level control. They typically overcome the problems caused by products sticking to the sensor and the need for continual readjustment. This Series has been extended with the new Easy Teach range, with housing lengths that can reach deeper into containers. These sensors have a G 1 1/2-in process connection, and are available in lengths up to 2,000 mm. They are suitable for both wet and dry areas. — *Rechner Industrie-Elektronik GmbH, Lampertheim, Germany*
www.rechner-sensors.de

Remove vapors from gases with this line of disposable filters

This new line of Balston In-Line Disposable Adsorption Filters (photo) is designed to remove vapors from gases. Hydrocarbons, ketones, carbon dioxide, ammonia, mercury, methanol and freons are just a few of the many vapors that can be adsorbed. Each filter is capable of handling up to 50 psig operating pressure in gas service and up to 70 psig in liquid service. The units come standard with a 1/2-in. tube connection and are constructed in nylon. The filters can be used for sample analysis, venting applications, emissions monitoring, and direct food contact applications. — *Parker Hannifin Corp., Haverhill, Mass.*
www.parker.com

This dosing pump features a hydraulically activated diaphragm

Primeroy L (photo) is the second product of this firm's range of compact industrial dosing pumps. It is designed around the GSD (Global Security Device) diaphragm liquid end, which provides a triple hydraulic security: internal pressure safety valve; diaphragm controlled hydraulic oil refill; and protection valve preventing the diaphragm from overrunning and extruding. The pump provides flowrates of 3,300 L/h with a maximum pressure of 45 bars. The pump is compliant with the API 675 and ATEX CE EX II 2G c T4 standards. *Milton Roy Europe, Pont-Saint-Pierre, France*
www.miltonroy-europe.com

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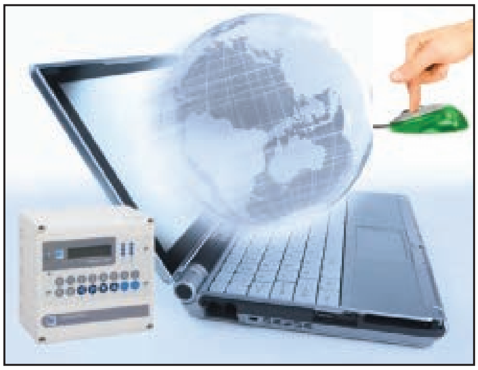
Herbold Mechersheim

Siemmens

Michell Instruments

FF-Automation



Shred big parts with this compact system

HR 102 P (photo) is a new single-shaft shredder that requires minimal space for shredding bulky hollow bodies, such as barrels (up to 220 L), purgings, tops and tails occurring during the production. Another application is bulky thermoforming waste, large injection-molded parts, and loose film waste. In addition to the conventional horizontal pushing device, this shredder has an additional pneumatically operated pushing device acting from above that has a positive effect on the material being sized by the rotor. If quality granulate is required, it is also possible to add a subsequent low-speed granulator from the firm's machine series. — *Herbold Mechersheim GmbH, Mechkersheim, Germany*

www.herbold.com

A dew point transmitter for when the pressure is on

The Easidew T.X. dew point transmitter (photo) has been enhanced to take accurate measurements in pressures of up to 450 bar (6,500 psi). The device is a fully configured and calibrated moisture transmitter that can be instantly incorporated into an air or gas management and control system. The unit incorporates an Advanced Ceramic Moisture Sensor coupled with advanced microprocessor-based measurement circuitry to form a fully calibrated and interchange sensor transmitter. Calibration exchange, or service, can be affected in seconds, even by untrained personnel. Ongoing operating costs are said to be low because of the transmitter's stability and reliability. Typical applications include compressed air dryers, hydrogen content in power generators, industrial gas manufacturing and supply. — *Michell Instruments, Ely, U.K.*

www.michell.com

A low-cost solution for remote monitoring and control

The AutoLog ControlMan (photo) uses existing GSM/GPRS and internet networks for communication, so users do not need to invest in their own networking, server or maintenance staff. Everything is offered as remotely hosted service. Users can simply open a web browser from any PC and log in to monitor and control their remorte targets. Services include all the standard SCADA features, such as alarms, trends, reports, controls and process views. — *FF-Automation Ltd., Vantaa, Finland*

www.ff-automation.com

This module lets flowmeters communicate via fieldbus

This firm has developed a new communication module (photo) for connecting flow instruments to Foundation Fieldbus (FF). The module is suitable for the series of Sitrans F M 6000 and Sitrans F C MASS 6000 devices, which are part of the USM II (Universal Signal Module) family. Based on the plug-and-play principle, the user simply clicks the module into the mount of the instrument. In addition to the new FF module, there are additional modules available for Profibus PA/DP, HART, Modbus RTU and DeviceNet. — *Siemmens Industry Automation Division, Nuremberg, Germany*

www.siemens.com

This water distribution system is pre-validated

Nexus (photo, p. 32I-3) is a range of standard, packaged, pre-validated distribution systems for purified water and water for injection (WFI), providing flowrates up to 30 m^3/h. Each package is complete with an inverter-driven pump, ASME BPE pipework, double tube-sheet heat exchanger and control panel. The hygienic design and fabri-

Veolia Water Solutions and Technologies


K-Tron

cation in 316L stainless steel are fully compliant with GAMP, ISPE, cGMP and FDA requirements. Standard instrumentation consists of conductivity monitoring, temperature control and a loop-return flowmeter with options for TOC (total organic carbon) and ozone monitoring. Sanitation is performed either by electrolytically generated ozone (with ultraviolet O_3 destruction), or hot water at 85°C (121 for WFI). — *Veolia Water Solutions and Technologies, Saint Maurice, France*
www.pharma.veoliawaterst.com

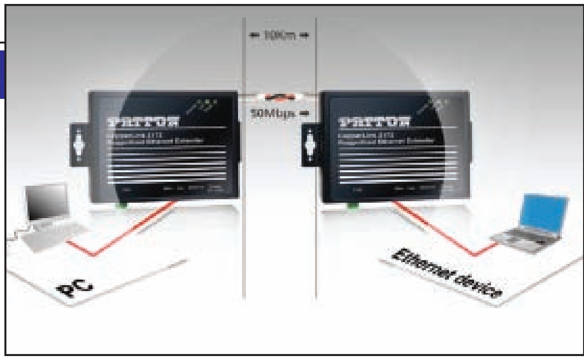
An enhanced way to feed small quantities of ingredients
An enhanced version of this firm's micro-ingredient feeder MT12 (photo) is now available in both pharmaceutical and non-pharmaceutical models. The system accurately feeds free-flowing or difficult to handle powders at flowrates as low as 20 g/h and as high as 2 kg/h, depending on the material. Both loss-in-weight and volumetric feeder models are available. Among the new enhancements are: a new inverted hopper design (negative cone), to aid material flow; a revised bottom agitator design driven from below the sealed shaft; a new sanitary scale design, which includes internal cabling and strong frame for better stability and accuracy; and a draft shield with loss-in-weight models for feeding at very low rates. — *K-Tron (Switzerland) Ltd., Niederlenz, Switzerland*
www.ktron.com

Cut costs when operating with this vertical pump
The Goulds VRS vertical rubber-lined cantilever sump pump is said to set new standards for energy efficiency and other costs. The VRS liners, impellers and casing halves are all interchangeable with the firm's SRL horizontal pumps, resulting in reduced parts inventory and maintenance costs. The VRS vertical pump also allows for liner replacement without requiring a change of the entire pump casing. The impellers are built with tighter tolerances than other vertical pumps, which improves the operating efficiency and saves up to 40% in energy costs, says the manufacturer. The VRS pumps are available in 2-, 3-, 5- and 6-in. dia. with 4 and 6-ft lengths. They can handle duties with up to 120 ft head, solids up to 1/4 in., and 75 psi working pressure. — *ITT Corp., White Plains, N.Y.*
www.itt.com

Comprehensive rheological solution for the petrochemical sector
In December, this firm introduced a comprehensive portfolio for the petrochemical industry that enables analyses of crude oil through refined products, such as bitumin. The firm offers a range of accessories for its rheometers so customers can, for example, simulate conveyance conditions in pipelines. A variety of pressure sensor systems, for pressures up to 40 bars and temperatures to 300°C, is available as well as a chemically resistant Hastelloy version. The RheoScope module for the Haake Mars rheometer platform enables simultaneous measurements of rheological characteristics and structural formations. This capability allows users to learn more about crystal growth in crude oil (waxing), to help optimize the flow of oil through pipelines. — *Thermo Fisher Scientific, Inc., Karlsruhe, Germany*
www.thermofisher.com

New Products

Amplicon



Allison Engineering

Air sampling when sterility is a must

Good Air-monitoring Practice (GAP) requests that all the material used for the microbiological monitoring of the environment is sterile, and sterilization compliance must be documented for the inspector authorities. The Dispo-Head sterile disposable aspirating head for microbiological air samplers of this firm's SAS family has been produced to meet these GAP requirements. Each unit is individually packaged and includes a sterilization certificate. One cubic meter of air can be sampled in about three minutes, when used with the DUO-SAS-360. — *International Pbi S.p.A., Milan, Italy*
www.internationalpbi.it

Monitor industrial effluents with this conductivity sensor

The InPro7250PFA inductive conductivity sensor is engineered to endure the most hazardous conditions while screening for manufacturing seepage. It features a hermetically sealed calculation system and a safeguard for maintaining stable conductivity for difficult-to-measure developments in pulp and paper processes and industrial wastewater. It consists of two high-precission coils hermetically sealed in a chemically resistant polymer matrix, and is inert to strong mineral acids, inorganic bases and oxidizing agents and salt solutions. — *Mettler Toledo, Greifensee, Switzerland*
www.mt.com

Monitor moisture content with this NIR gauge

Critical control of moisture content can be used to control product quality, improve productivity, save fuel consumption and optimize drying processes. The CM710e range of Ethernet-enabled, online gauges uses near-infrared (NIR) technology to measure moisture. The system's operator workstation enables local interaction with an individual gauge, while the human-machine interface provides supervisory access to up to 16 Series 710e gauges within the same network. — *NDC Infrared Engineering Ltd., Maldon, U.K.*
www.ndcchemicals.com

Connect Ethernet over distances up to 10 km without drivers

This firm has added a new range of Ethernet Extenders (photo), which uses DSL technology to extend communications links up to 10 km over a single pair of copper wires. The units can operate transparently as part of an existing network with no drivers to install or complex setup procedures. All IP traffic that could be sent across a standard patch cable can be sent across an Ethernet Extender link. The extenders can be used to connect two existing LANs or to connect two isolated Ethernet devices together — one of which is typically a PC running application software. — *Amplicon, Brighton, U.K.*
www.amplicon.co.uk

Ensure enclosure safety with this purge system

The newest version of the x-purge is designed to achieve hazardous area requirements for general-purpose enclosures and their internal electronics. The unit does so by continuously purging the enclosure with compressed air or nitrogen. The positive pressure in the enclosure ensures gas flow from inside to outside and eliminates the possibility of flammable gases re-entering the enclosure. The unit is constructed from stainless steel, which offers the benefits of strength and corrosion resistance. The x-purge is certified under NFPA Class 1, Div. 1., and another version, the z-purge, is certified under NFPA Class 1, Div. 2. — *Eclipse Technologies, Inc., Houston, Tex.*
www.eclipsetechnologiesinc.com

Check for leaks over a wide area with this laser-based system

The portable Boreal Laser Gas Finder 2 (photo) is ideal for open-path, ambient gas detection and multiple-path monitoring applications. The unit is permanently calibrated, can be easily setup and operating in less than 10 minutes. An automated scanning mount enables full 360-deg. horizontal and 120-deg. vertical scanning. Typical applications include identifying methane hotspots and measuring CH_4 fluxes in landfills, quantifying leaks of CH_4 in natural-gas production and processes, quantifying CH_4 and NH_3 emissions and measuring CH_4 and CO_2 from area sources. — *Allison Engineering, Basildon, U.K.*
www.allison.co.uk

Improve pipetting with realtime sensing

E-Man Hybrid is a new generation pipette incorporating the operational simplicity of a manual pipet with realtime sensing technology. That means the pipette allows for realtime monitoring of the position of the piston and the amount of liquid dispensed. With continuous volume tracking in place, the pipette offers great value for titrations and partial dispensing, as well as for measuring aspirated fluids. GMP/GLP functions, such as saved calibration and service alerts, are built in. Precision is increased because a visual alert indicates inadequately executed pipetting cycles. — *Rainin, a Mettler Toledo Co., Greifensee, Switzerland*
www.mt.com

This analog signals conditioner comes in a small package

With the new miniMOORE family of multichannel signal conditioners, up to four low-cost I/O channels are delivered in a 1-in. footprint — equivalent to 0.25 in./channel. Providing 1,000 Vrms input-to-output and channel-to-channel signal isolation, the complete miniMOORE family can be used to isolate, convert, boost and split analog signals. The metal housing protects against radio frequency and electromagnetic interference (EMI), which may be present from walkie-talkies, motors, transformers and fluorescent lights. The signal conditioners come in two- and four-channel versions. — *Moore Industries-International, Inc., North Hills, Calif.*
www.miinet.com ■

Gerald Ondrey

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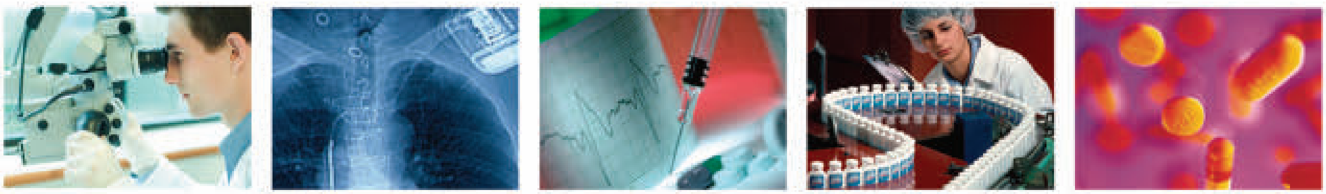

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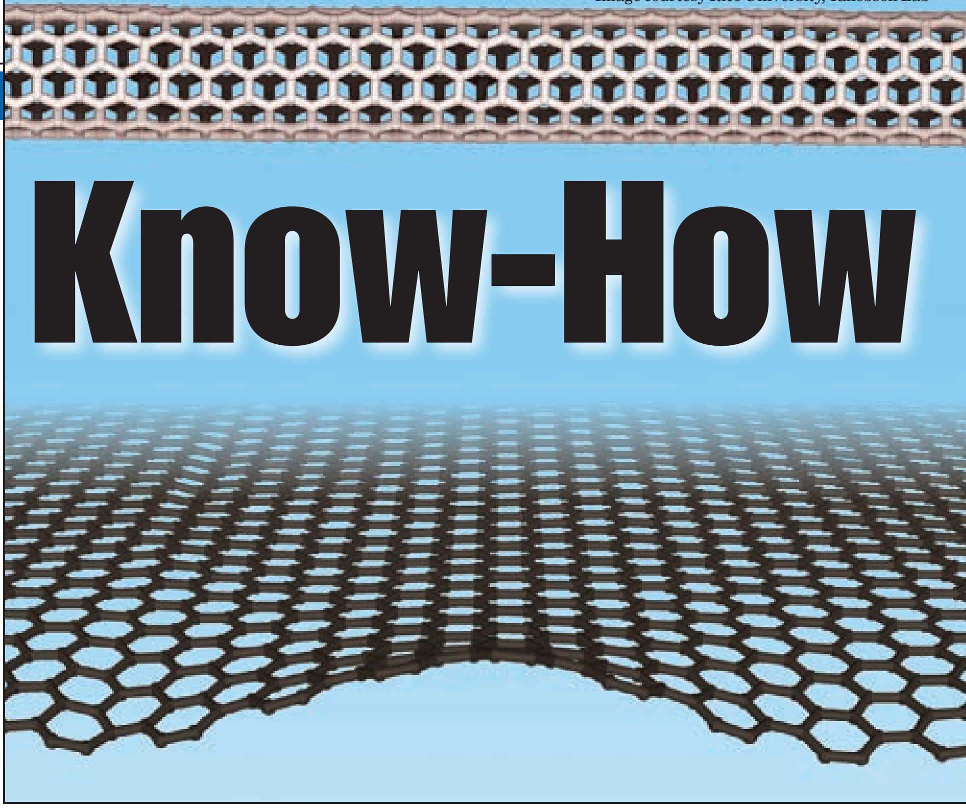
Cover Story

NANO Know-How



This brief introduction to nanotechnology provides a basic understanding to those new to the field

Image courtesy Rice University, Yakobson Lab

FIGURE 1. A graphene sheet (bottom) is a sheet of sp2-hybridized carbon atoms. A single-walled carbon nanotube (top) is equivalent to a graphene sheet rolled into a cylinder

Charles R. Richard
Patent Attorney

Most chemical engineers and chemists are aware of the recent excitement generated by nanotechnology, but many may wonder what all the fuss is about. Nanotechnology deals with small, nanometer-scale objects, which chemical engineers and chemists deal with everyday, at least in the form of atoms and molecules. Even so, those who realize that there is some distinction are often a little unsure of the "nuts and bolts" involved.

Unfortunately, as with many new technology areas, much of the literature on nanotechnology is either highly specialized or contains much hype and little substance. It is therefore difficult for those new to the field to get a general understanding of it using reasonable time and effort. This article is intended to help fill in the gap, with enough of the basics covered to provide a useful overview applicable to a chemical engineer's field. The main topics covered are the definition of nanotechnology, some history, interactions, characterization, materials, applications, safety concerns and trends.

DEFINITION

It is important to actually define nanotechnology, which in itself may alleviate confusion that many have on the subject. The definition given here is based on that used by the National Nanotechnology Initiative (NNI; Arlington, Va.; www.nano.gov).

Nanotechnology may be defined as research or technology development at the atomic, molecular or macromolecular levels, in the length scale of about 1–100 nm, resulting in: (a) the creation and/or use of materials, structures, features, devices or systems that have novel properties and/or functions because of their size or (b) the ability to control or manipulate on the atomic scale.

It is important to note that nanotechnology is concerned with items of small size where the size factor relates to their having "novel properties and/or functions". As shall be described later, the "novelty" is usually noticeable in some manner from a macro point of view. Here, "novel" refers to things observable that would be unexpected to those previously unfamiliar with nanotechnology; examples of this will be given below.

Nanotechnology is also concerned with controlling and manipulating on the atomic scale, as on a more individual particle rather than a collective basis, even visually in some sense. It is distinct from the "coarser" and more "free-form" technologies that chemical engineers and chemists usually use to manipulate atoms and molecules.

Nanotechnology has been described as being in the border area of sizes important in physics and electrical engineering, chemistry and chemical engineering, biology and biotechnology, as well as mechanical engineering. To put the size range here into some concrete perspective, the diameter of a hydrogen atom is about 0.1 nm; that of a silicon atom is about 0.33 nm; the diameter of a carbon nanotube, discussed later, is often about 1 nm; the minimum feature on microchips is less than 90 nm in size; the size of a smallpox virus particle is about 100 nm; the wavelength of visible light is from about 400 to 700 nm; and the size of a small bacterium is about 1,000 nm or 1 micron.

NANOINTERACTIONS

What we normally perceive about the world on the "macro" level might be thought of as some sort of average or composite of what goes on at the "micro" level. However, what is observed on a macro level is often very different in many respects from what would be observed on a micro level. Using more sophisticated terms, the macro is the world of classical physics and chemistry, and the micro is the world of quantum physics and chemistry. For our purposes, the world of nanotechnology can be thought

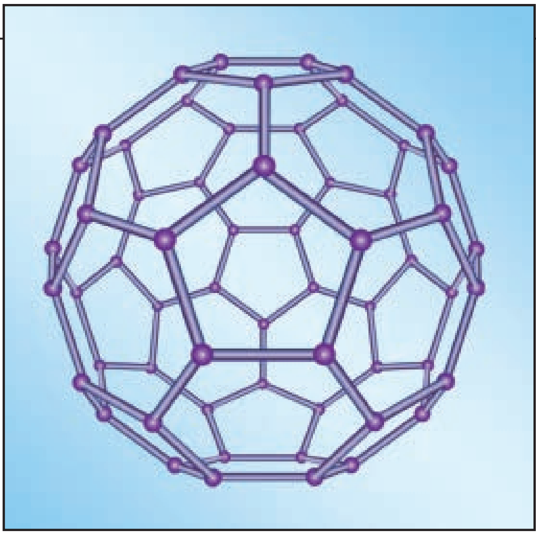


FIGURE 2. Nanoparticles have dimensions between 1–100 nm. Here, a nanoparticle known as a Buckyball is shown; it is a spherical particle made up of carbon atoms

Schrodinger equation

$$-\left(\frac{h^2}{8\pi^2 m}\right)\left(\frac{d^2\psi(x)}{dx^2}\right)+U(x)\psi(x)=E\psi(x)$$

where,

h = Planck's constant
m = particle mass
ψ(x) = wave function; $/\psi(x)^2$ is the probability of finding the particle at location *x*
x = dimensional coordinate
U(*x*) = potential energy at *x*
E = particle energy at discrete values corresponding to allowable energy levels

of as falling at the interface of these other two worlds. Stated another way, nanotechnology is concerned with a level smaller than the bulk, but at or slightly above the atomic.

A detailed discussion of quantum principles is beyond the scope of this article, but a brief description of some main features is helpful in understanding nanotechnology.

According to the de Broglie theory, particles of matter may sometimes act as waves, as does light. At the same velocity, smaller and lighter (micro) particles, such as electrons, have longer and more noticeable wavelengths than larger and heavier (macro) particles, such as baseballs. Noticeable wave behavior of particles is usually a phenomenon of micro as opposed to macro particles.

The basic equation of mechanics describing the quantum situation is the Schrodinger equation. This equation may be thought of as an energy balance. Its one-dimensional, time-independent form may be expressed as the equation in the box above.

Many interesting and often counterintuitive conclusions about the world from a quantum perspective can be derived from applying the Schrodinger equation in an appropriate form in various situations. One such conclusion worth noting, since it is the basis for an important instrument to be discussed later, is the existence of electron tunneling through a potential barrier. Such a barrier exists between two slabs of metal separated by a short gap. In this situation, the particle in question would be an electron at the surface of one of the metal slabs, *U* would be the potential energy barrier presented to the electron by the gap, and *E* would be the energy of the electron with $E < U$. Classical physics would say that the electron had insufficient energy to cross the barrier, but application of the Schrodinger equation reveals that there is some probability that the electron would cross the barrier. Under the right conditions, this electron tunneling results in an experimentally observable current; such a current is the basis of Scanning Tunneling Microscopy, which is discussed later. The solution of the Schrodinger equation in this and other situations may be found in most standard engineering physics and physical chemistry texts, as well as in standard texts on quantum mechanics. The solution applicable to tunneling in Scanning Tunneling Microscopy is considered further below.

It is important to note that the situation in tunneling is not analogous to situations where some particles in a large collection have sufficient energy to cross a barrier, while the average energy of the particles is less than required. Consider particles of reactants in a chemical reaction having different energies, some above and some below the energy of activation barrier for the reaction; in chemistry, we learn that only particles that actually have the energy sufficient to get over the energy barrier will react. In tunneling, none of the electrons in question has energy larger than the barrier. It is the wave nature of the electrons that makes tunneling possible; recall the relation of the wave function of the Schrodinger equation and probability of particle location given above. If readers feel that this is too strange to be true, they are in good company; it is said that Einstein once remarked concerning the probabilistic nature of quantum mechanics that he did not believe that God played dice with the universe — but observable electron tunneling seems to say otherwise.

NANOCHARACTERIZATION

There are many ways to characterize nanomaterials, including visualization in some sense. Some methods are very similar to those that have been used in characterizations of more conventional materials for many years. This section will concentrate on some of the newer and more highly specialized instruments and techniques that are most popular at the moment. They are all some form of microscopy or spectroscopy, and some of these techniques have been adapted for manipulation of individual nanosized particles as well. Nanocharacterization instruments and techniques are useful in research, development, manufacturing and quality control in nanotechnology.

Most readers have probably used a conventional light microscope and other analytical techniques — usually spectroscopy — that use or measure some type of radiation or beam. The basic concepts of all of these are in many ways applicable to what will be covered here.

Conventional light microscopy has only very limited direct use in the characterization of items important in nanotechnology. The basic limitation, its resolution, is proportional to the wavelength of the light being used. Ultraviolet light, as opposed to visible, may be used for an improvement given its shorter wavelength. Since refractive index is also a factor in determining resolution, oil immersion may be used to alter the refractive index to improve the situation as well. The fundamental limitation on resolution of ordinary light microscopes is usually given as half the wavelength of light used; the limit is sometimes given as 200 nm which is about half the smallest wavelength for visible light. This makes it of limited use in nanotechnology, which has a usual upper limit of interest of 100 nm. There are some newer near-field techniques, however, that are said to get this limit down to a tenth of the wavelength used.

Electron microscopy

A further improvement on microscopy can be achieved by recognizing that electrons have a wave-like character. Therefore, they can be used in microscopy like light. Electron wavelength is inversely proportional to the square root of the electron's acceleration voltage. Resolutions of 1 nm down to 0.1 nm have been reported for electron microscopes. These microscopes have been used in some form for many years; however, they have been recently improved in many respects. One important difference between electron microscopes and ordinary light microscopes is in the lenses used; electron microscopes do not use glass lenses, but rather some form of electromagnetic or similar lenses.

There are two major kinds of electron microscopy: Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM). The main difference is in what the electrons do or which electrons are used in detection. In SEM, the electron beam scans across the field of interest, and the electrons that are knocked off the surface atoms — or sometimes from a little deeper as well — and those from the beam that bounce off the surface are detected and used in characterization of surface or deeper features.

In TEM, the electron beam is aimed at the field of interest, and the transmitted electrons — those that pass through the sample and perhaps some knocked off sample atoms and through the sample — are detected for characterization. Of the transmitted electrons, three types may be detected for different purposes: the unscattered carry information about the sample thickness, the elastically scattered carry crystallographic type information and the inelastically scattered carry information on composition, bonding and atomic spacing. TEM is usually more successful when thinner samples are used.

Scanning tunneling microscopy

Another technique that is very popular in nanocharaterization is Scanning Tunneling Microscopy (STM), which was mentioned earlier in the discussion about the Schrodinger equation. In STM, a sharp metallic tip is brought in close proximity to a sample with either the tip or the sample or both capable of being precisely moved to allow for a tightly controlled gap and scanning of the sample surface. The main limitations of this technique are that the sample must be reasonably electrically conducting, and only a small surface area can usually be scanned.

From the solution of the Schrodinger equation for this situation, it can be shown that the probability of tunneling, and hence tunneling current, is proportional to $\exp[-1.025\, d(U - E)^{1/2}]$, where U and E are expressed in electron volts (eV) and d is the distance between the tip and sample in angstroms (1 angstrom equals 0.1 nm). $(U - E)$ can be approximated by the average work function of the tip and sample; the work function is the amount of energy required to remove an electron from a surface. From this proportionality, we may determine many facts about a particular surface. For example, taking 5 eV as a normal average work function, the tunneling current will change by an order of magnitude for each 1 angstrom change in d. This sort of data indicates changes in surface height topography and yields surface maps on a very small, even atomic scale of resolution. Resolutions of 0.1 nm have been reported for STM. This technique has been adapted to chemical analysis, and even manipulation, down to the single-molecule or even atomic level.

Atomic force microscopy

A newer and very popular technique is Atomic Force Microscopy (AFM). This technique involves bringing a cantilever with a sharp tip over the surface of interest; the tip-surface interaction, a force, results in deflection or oscillation of the cantilever, which is measured. An analogy for this is a phonograph arm with a needle reading a record surface.

Because of the great sensitivity of measurement possible, very detailed maps of surfaces can be obtained. The technique can be used to sense surface topography, for height or other properties, to very small resolutions. Spacial resolutions well below 1 nm have been reported — there is at least one report of a figure as low as 0.01 nm, which, if accurate, would be truly remarkable, considering this is one-tenth the diameter of a hydrogen atom. Interestingly, the tips may be chemically modified and adapted accordingly for very detailed chemical or biological sensing. One advantage of AFM over STM is its ability to analyze non-electrically conducting samples.

Other techniques

Other techniques useful in nanocharacterization involve various surface bombardments with either charged particle beams or electromagnetic waves, such as focused ion beams, focused electron beams or X-rays. Ions or electrons from the beam or sample coming off, as well as photons, X-rays, fluorescence or the like may be detected and used to characterize properties of the sample with various resolutions, depending on the exact technique. These properties may simply be surface height topography, but at times might also be something else, such as chemical composition — surface or otherwise. These techniques are often termed spectroscopic, and may be more familiar to readers, at least in general principles, than some of the microscopic techniques discussed previously.

Specific examples include Scanning Ion Mass Spectroscopy (SIMS), where an ion beam hits a sample and ions knocked off the sample are detected; Particle Induced X-ray Emission (PIXE), where a high energy ion beam (such as of helium ions) hits the sample and emitted X-rays are detected; and X-ray Photoelectron Spectroscopy (XPS), where samples are hit with X-rays and photoelectrons coming off the sample are detected. These three specific techniques are all very good for providing detailed chemical analyses, especially over small spacial ranges.

TABLE 1. ISSUED U.S. PATENTS CLAIMING NANOTUBES, NANOPARTICLES AND/OR NANOWIRES IN VARIOUS YEARS			
Year	U.S. Patents Issued in Year	Year	U.S. Patents Issued in Year
before 1982	0	2004	406
1982-1991	7	2005	482
1992-1996	43	2006	665
1997-2001	276	2007	828
2002	171	2008	885 (estimated)*
2003	287		

*Data was collected on 10/30/08 with the 2008 number as of then at 737.

The types of microscopy and spectroscopy described herein and combinations of these, as well as certain others, may be used in nanocharacterization, with the probable exception of most light microscopy as noted above. Nanocharacterization is a fertile area of development in itself. As noted previously, many of these techniques have been adapted for nanoscale manipulation.

NANOMATERIALS

If one defined nanomaterials simply as materials having constituent particles with at least one dimension between 1 and 100 nm, then many, if not all, materials would be included depending on the interpretation of "constituent" particles. As discussed earlier, size is not quite enough to define things in the nanoworld. We must also consider if the material has some novel properties and functions due to particles, or even parts, in the 1 to 100 nm size range.

There are many classes of materials that could be described here, but we will focus on some very basic ones: quantum dots, nanowires, nanotubes, nanoparticles and a mention of nanoassemblies. Among these categories may be some overlap.

Quantum dots

A quantum dot, also called a Qdot, is a nanosized semiconductor of such dimension that there is quantum confinement of electrons in all directions; it is like a point or zero-dimensional object. As a result, it has many peculiar properties. One that has been dramatically demonstrated is the difference in coloration of fluorescence emissions of dots of the same material, depending on the size of the dot. These materials appear to have great application potential in electronics and in quantum computing; the latter is a computer architecture that uses quantum states as its basis with — theoretically for now at least — enormous capacity improvement over current systems.

Nanowires

A nanowire is composed of thin lines of some material, between 1 and 10 nm (possibly somewhat larger) in two dimensions and much longer in a third dimension, usually 1,000 times or more so. Thus, they are wire-like and not sheets, so in a sense they are one dimensional objects. Since quantum-mechanical effects are important at these dimensions, they are sometimes called quantum wires.

There are many types of nanowires: metallic (such as Pt), semiconductors (such as Si or GaN) or even insulating (such as SiO_2). There is a class called molecular nanowires, which may be organic or inorganic based, with molecular type subunits, but this nomenclature is usually limited to electrical conductors measuring less than 3 nm in two dimensions. Nanowires may exhibit peculiar properties like quantum confinement of electrons (since they are basically one dimensional), quantitized conductance and edge effects relating to conductance. They appear to have great potential for use in very small electrical circuits and as additives in composite materials.

Nanotubes

A nanotube for purposes here will be limited to carbon nanotubes (CNT's), which have had considerable attention lately; other types are usually classified as nanowires, as technically are CNT's as well. CNT's are basically made up of one or more graphene sheets (Figure 1) separately rolled into cylinders that may be closed at one or both ends. A graphene sheet is a sheet of bonded carbon atoms (sp2 hybridized); graphite is made up of stacks of graphene sheets. CNT's are considered to be part of the fullerene family, which represents a distinct form of carbon. Buckyballs, comprised of all carbon and shaped like soccer balls (Figure 2) are also in this family. CNT's are usually around 1 nm in diameter, but much longer than this — maybe even up to a millimeter or so.

CNT's come in several forms. There are both single-wall and multi-wall CNT's; the single-wall type can be visualized as one rolled up sheet of graphene and the multi-wall as two or more nested rolled up sheets of graphene. Based on how the graphene sheet is wrapped when forming a CNT cylinder (its helicity), the result is termed zigzag, chiral or armchair. Interestingly, the type of wrapping affects some properties of CNT's; they are either metallic (and electrically conducting) or semiconductors, and all armchair types are metallic.

Carbon nanotubes may be made by arc discharge, laser ablation or chemical vapor deposition. The single-wall variety is usually favored because of its electrical properties and may be separated out from other forms that are made along with it by centrifugation and microfiltration. A double-wall variety may preserve some of these desirable electrical properties and has added chemical resistance. It is possible to functionalize CNT's. Van der Waals forces are very important in CNT's, making them stick and clump together. Because of this, they are often stored in surfactants to keep them well suspended and separated. CNT's, especially the purified single-walled type, are still rather expensive (probably many dollars per gram), though prices have recently started to decrease.

CNT's have some very special and desirable properties relating to electrical conductance, strength and elasticity. Carbon nanotubes have been found, in at least some forms, to have electrical conductance at least as good as copper (but some reports say much higher) and thermal conductivity at least that of diamond; it is possible that CNT's in some form may exhibit "ballistic" — very high to nearly perfect — electrical and thermal conductivity. Interestingly, CNT's may exhibit good thermal insulating properties lateral to their axis, but good conductivity along it. In at least some forms, they are some of the strongest and stiffest materials known, perhaps 100 times as strong as steel, but much lighter. They are not as resistant to compression. CNT's have great potential for use as structural materials, such as in the space elevator and in more practical places, as an additive in composites, in drug delivery and in electrical circuits.

Nanoparticles and nanoassemblies

Nanoparticles are particles that have all dimensions between 1 and 100 nm and have novel properties as a result of their size. They may be made of many different materials.

In addition to the types of materials described here, nanomaterials include nanoassemblies, which are structures, features, devices and systems that can be thought of as more highly manufactured nanosized items.

Creating nanomaterials

Generally, nanomaterials may be made by either top-down methods like milling, or bottom-up methods like chemical vapor deposition or fine electroplating. Sometimes, these materials are made by refining conventional materials.

We can often learn from nature how best to make and even apply these materials. This has been called bio-mimicry. For example, the "self-assembly" that occurs in many natural — and by extension in some conventional synthetic processes — is worth study in this regard. This can include how a string of amino acids apparently folds by itself into the correct conformation to form an active enzyme, the formation of lipid bilayers and micelles, and the use of miniature templates as in DNA or protein synthesis or perhaps virus particle assembly. It is possible to have nanomaterials that are hybrids of natural and synthetic materials; as an example, DNA may be coupled with synthetic particles in some identification techniques.

APPLICATIONS

The possible applications of nanomaterials are nearly limitless. Only some of the applications that currently exist or are possible in the future are described in this article.

Nanomaterials have great potential in many applications. Some products that currently use nanomaterials include computer hard drives, sunscreens, catalysts, coatings, sporting equipment, stain resistant pants, dental restoratives, quantum dot fluorescers, dressings for wounds, and even some cancer therapies. There are likely some sensors based on nanotechnology on the market by now and perhaps a "lab on a chip" using microfluidics as well. Additionally, there are many applications, such as in electronics, batteries, fuel cells, and photo cells that should be out in the market soon if not already available.

It is interesting to consider some applications mentioned here in more detail. Some sunscreens now contain nanoparticles of titanium oxide or zinc oxide; these materials were known for many years to work well in sunscreens, but had the drawback of being bright white when in larger particle form, as many readers probably recall from sad experience. The nanoparticle forms work at least as well in this application and have the advantage of being transparent. As to catalysts, many crystalline materials have a different crystal structure when nanosized than when a bulk material, which can boost their catalytic effectiveness.

An interesting application of nanomaterials in coatings is the ceramic nanocomposite used by the U.S. Navy to coat main propulsion shafts on ships. The original shafts were wearing down in about a year, causing a serious maintenance problem. With the nanocomposite coating, the shafts were found to last at least four years with no signs of wear. Previously, no coating was found that would survive in the environment, protect the shaft and not cause a corrosion problem. It is believed that the size of the particles allowed them to pack tighter in this service, making the coating long wearing and successful. A similar reason may explain how nanosized dental restoratives work.

Sporting equipment like tennis racquets, baseball bats and golf clubs seems to take advantage of CNT fibers for added strength. Silver nanoparticles are the nanoagent at work in the wound dressings mentioned, silver having a good anti-bacterial effect; however, note the possible safety issue mentioned for another application of these particles below. The nanotechnology involved in cancer therapies is often the delivery agent of a previously known drug, the size of the platform being an important factor.

SAFETY CONCERNS

As is common with new technologies, there is concern that nanotechnology might present significant safety issues. While it may be unwise to be alarmists and risk missing some monumental breakthroughs, given that nanotechnology is very new and unexplored territory, it would seem prudent to proceed with some caution until the area is better understood.

Given the small size of nanomaterials, they might easily and unintentionally penetrate the bodies of humans and other animals via inhalation or other means. There is some indication that nanomaterials like carbon nanotubes cause severe inflammatory responses when inhaled by animals, which leads to fear that diseases similar to silicosis, asbestosis or related conditions might result in those sufficiently exposed. Of course, even if these potential hazards are real, it is possible that the materials could still be used with proper handling, as is the case with many chemicals and nuclear materials. Further study on the safety of nanomaterials is warranted.

There is a doomsday scenario proposed involving nanotechnology that should be mentioned, even if it might be a little far fetched. In this scenario, the world and all its resources are consumed in the runaway production of self-replicating nano-sized robots. All that remains is a "grey goo," a term coined by Eric Drexler.

Leaving the issue of grey goo aside, it might be useful to consider how we may be caught by surprise in less dramatic but still problematic ways, due to undesirable consequences of nanotechnology products. As an illustration, consider that there has been recent concern focused on socks treated with silver nanoparticles to control foot odor. It is suspected that these nanoparticles come off during washing and might kill off bacteria that break down waste in sewage treatment plants. Whether or not such a problem can be foreseen, we need to keep our collective eyes open when dealing with new technology. There have been discussions, and maybe by now some action, on establishing industry-wide safety councils and safety standards.

HISTORY OF NANOTECHNOLOGY

Surprisingly, the history of nanotechnology may actually go back many centuries, perhaps even to ancient times, in at least some sense. There is evidence that gold nanoparticles were used in coloring glass in medieval times and possibly even during the days of the ancient Romans; here the size of the particles is related to the color. More recently, but still decades ago, carbon nanoparticles, better known as carbon black, were first used in making tires. Fumed silica is probably another example of a nanoparticle that has been made for many decades. It might be argued that people did not fully appreciate what they were doing in these examples of early applications of nanotechnology, but they were actual applications nonetheless.

Many regard that nanotechnology really came into being when the physicist, Richard Feynman, delivered his 1959 speech, "There's Plenty of Room at the Bottom"; the text of the speech is available on the web and is well worth reading. At the time of writing, a transcript of the speech was available at www.zyvex.com/nanotech/feynman.html. Feynman described many things that might be attempted on a very small scale. It is truly amazing how much foresight Feynman had, especially when keeping in mind that many relevant facts that we take for granted today as common knowledge were not known or well understood at the time, and many characterization techniques were in early stages of development at best. These were the days when the limited special effects of the original Star Trek series would have seemed sophisticated.

Since the 1959 Feynman speech, knowledge and applications of nanotechnology have grown dramatically. One simple but truly exciting example of these developments was the 1989 project by IBM workers to spell out the letters "IBM" in atoms, which was done by manipulating single atoms of xenon on a nickel surface using a scanning tunneling microscope. A picture of the result is available on IBM's website (www-03.ibm.com/press/us/en/pressrelease/20360.wss). From a more practical standpoint, many applications have actually resulted in products currently available on the market as described herein. ❑

TRENDS

Nanotechnology is currently applied in many areas, and these application areas each has its own direction and growth rate. Detailed analyses of trends in such a complex field is beyond the scope of this article, but it would be helpful to see how one area of interest has progressed. A subset of nanomaterials — nanotubes, nanoparticles and nanowires — is chosen here as the illustration, with relevant U.S. patent issuances as indicator. These data are given in Table 1 and show that this area is growing at a significant rate.

It might be useful to consider how biotechnology developed when trying to predict how many big-picture subsets of nanotechnology will fare. Biotechnology is one of the newer technology areas and attracts the attention and imagination of the technical community and even the general public. It could be argued that it is being subsumed into the larger umbrella group of nanotechnologies to some extent as well. Thus, it makes for a good study model here.

Critics regard the development of biotechnology as messy, expensive and over-hyped in many respects, and see it as disappointing, considering efforts and money expended versus useful products brought to market. Whether or not this is fair, it is clear that all is not smooth sailing for biotech. Most readers are probably aware of the public relations issues that biotechnology has had with genetically modified foods. There has also been much controversy and expensive litigation concerning biotechnology patents; many applicants seemed to overreach and over claim, thus making development difficult in many respects. In one memorable court case involving Cox-2 inhibitors before some were found to be dangerous, a judge remarked that the patent application in question was more research plan than research results; the claims in controversy were invalidated, but not before a great deal of time and money were spent on the case.

Anecdotally, nanotechnology examiners at the U.S. Patent Office complain that the "over-claiming disease" has spread to applications they see. Hopefully, the level of hype, waste and public relations missteps associated with biotechnology by its critics will not spread to nanotechnology as well, but as with all new "big things," the danger exists.

The estimated current and potential value of the market for nanotechnology and its products, as well as corresponding investment, is estimated at some astoundingly large numbers — suffice it to say that these are always reported in many billions of dollars or more. It may be a bit tricky to tell how accurate these estimates are, since some appear to count entire situations that have just a small nanotechnology content. It seems that hype has crept in here to some extent.

In any case, there is some real market potential here. Many national and regional governments and groups, industries and universities are getting seriously involved. On the national level in the U.S., we have the National Nanotechnology Initiative. The U.S. government has many labs involved in nanotechnology research, with one being the Institute for Nanoscience at the Naval Research Laboratory (NRL; Washington, D.C.; www.nrl.navy.mil/nanoscience). The NRL has been known to give very informative tours to the public that include demonstrations of some instruments and techniques described in this article.

There are states and regional groups in many parts of the U.S., as well as in other countries, that actively promote nanotechnology research and development. Many corporations, industry groups and universities in the U.S. and around the world have programs devoted to nanotechnology. ■

Edited by Kate Torzewski

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Acknowledgements

The author wishes to acknowledge Drs. Boris Veytsman and Samar Guharay, who provided excellent instruction and class notes in graduate nanotechnology courses he took from them at George Mason University, and Dr. Richard Colton, of the Institute for Nanoscience at NRL who gave an excellent guest presentation and a great hands-on tour of his nanotechnology lab at NRL as part of the aforementioned nanotechnology courses. Knowledge gained from these gentlemen was very helpful in preparing this article.

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Plate Heat Exchangers: Avoiding Common Misconceptions

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A solid understanding of the critical areas presented here will insure good performance

The use of gasketed plate-and-frame heat exchangers has gained tremendous acceptance in the chemical process industries (CPI) over the past 20 years due to their high heat-transfer coefficients, compactness and low cost. However, it is important for the engineer who is selecting this type of heat exchanger to be aware of critical areas in design or selection so that possible operating or maintenance problems can be avoided once the heat exchangers are in use. This article addresses these critical areas, which should be considered at the very beginning of the equipment-design task.

Today, while there are a variety of heat exchangers using thin, corrugated plate technology, the gasketed type of plate heat exchanger (Figures 1 and 2) is the one most familiar to the engineer and is therefore the focus of this article. The author will point out more recent design variations of corrugated plate technology that uses plate packs that are sealed without gaskets using brazed plates, laser-welded plates or newer, fusion-based sealing technology, which may allow the engineer to expand beyond the limitations of the gasketed plate type. In any case, it is important to note that high turbulence and high wall-shear stress due to flow in closely spaced corrugated plate channels is the key to the high heat-transfer coefficients and compactness for this general class of heat exchangers, whether they be gasketed or gasket-free.

Limitations of *P* and *T*

Most importantly, the engineer selecting gasketed plate exchangers must be aware of their temperature (*T*) and pressure (*P*) limitations. When plate heat exchangers were first developed in the 1930s, they were used primarily for dairy applications. In these services, low temperatures of 95°C and pressures of 3–5 barg were not of concern. To make the transition to industrial applications, gasketed-plate heat-exchanger manufacturers in the 1960s developed pressing patterns leading to "stiffer" plates and more secure gasket sealing techniques that allowed design temperatures and pressures of up to 115°C and 10 barg.

Since then, however, manufacturers have made significant strides in expanding the temperature and pressure envelopes within which these heat exchangers can safely work. Standard, gasketed plate-and-frame heat exchangers now routinely are available with elastomeric seals that can be used with confidence up to 180°C. Maximum design pressures for gasketed plate heat exchangers can reach in excess of 20 barg, which, while not viewed as high for some industries, probably covers 90% of most CPI applications.

As mentioned earlier, the development of brazed, laser-welded and fused plate technology has allowed the fabrication of gasket-free plate heat exchangers (Figure 3). This has expanded the operating boundaries of plate heat exchangers to temperatures of up to 550°C and pressures up to 54 barg. However, the overall application of welded-plate heat-exchanger technology is limited by fatigue characteristics of the plate if temperature or pressure cycling is a factor in the process for which they are considered. In addition, these gasket-free types should not be used for fluids that contain solids or tend to foul, since for most of them, the sealing methods used do not allow opening of the heat exchanger for inspection or cleaning. Still, for clean fluids in non-cycling services requiring compactness and efficiency and where design temperatures and pressures exceed the capability of gasketed types, these gasket-free plate heat exchangers are a valuable alternative. (See Part 2, pp. 44–47 for more on these types of heat exchangers.)

An easy to remember and good rule of thumb that the author likes to use when considering the limits for standard *gasketed* "plate and frame" heat exchangers is "350°F and 300 psig," for the design temperature and design pressure, respectively.

Fouling considerations

It has been demonstrated over the years by many sources (Ref. [*1, 2*] are typical) that plate heat exchangers exhibit — and can be designed for — much lower fouling factors than conventional shell-and-tube designs. This is due to the turbulence and high wall-shear stress that the fluids in plate heat exchangers exhibit, due to highly turbulent flow between corrugated, parallel plates. The author prefers, though, to clarify this greater fouling resistance as resistance to "micro-fouling" (that is, fouling due to sedimentation of suspended fine particles, scaling, crystallization or some biofilms). In this case, it is very important that the engineer bring to the attention of the manufacturer, who is carrying out the design of the plate heat exchanger, the presence of these phenomena and their fouling potential so that the manufacturer can design the plate heat exchanger for high wall-shear stress. Wall shear stress is a measure of the stress along the face of the corrugated plate expressed as a pressure (force/area). In a plate heat exchanger,

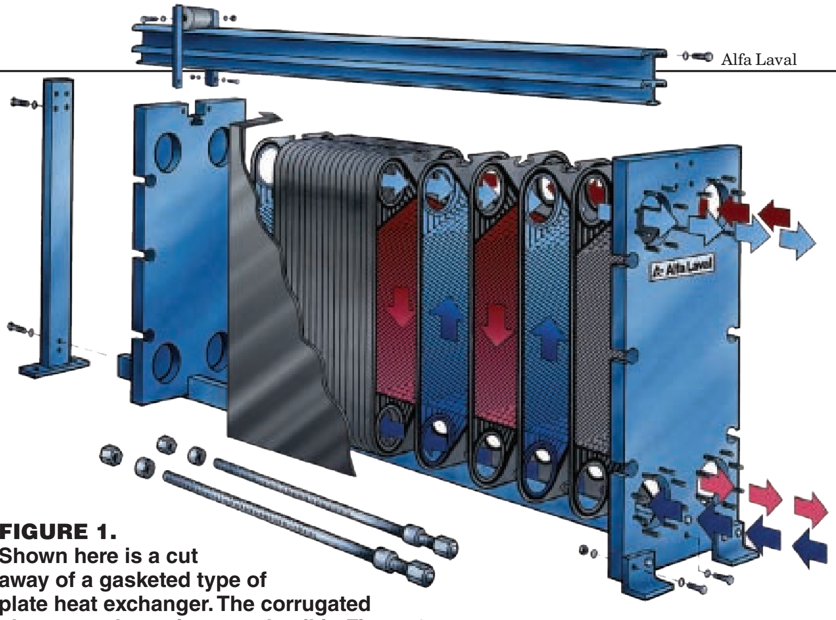

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FIGURE 1. Shown here is a cut away of a gasketed type of plate heat exchanger. The corrugated plates are shown in more detail in Figure 2

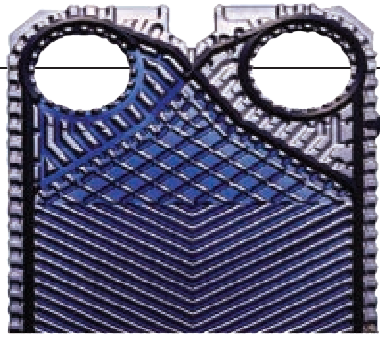

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FIGURE 2. Corrugated plates, such as the one shown here, are used in the most familiar type of gasketed plate heat exchangers

the wall shear stress, τ, is calculated using Equation (1):

$$\tau = (\Delta P \times s)/2L \qquad (1)$$

where

τ = wall shear stress, Pa or N/m^2 (SI), or psi (U.S.)

ΔP = pressure drop through plate heat exchanger, Pa (psi $\times$ 6,894 = Pa)

s = plate pressing depth, mm

L = effective plate length, mm (measured as centerline-centerline distance between top and bottom ports plus one port diameter)

The higher the wall shear stress that the plate heat exchanger is designed for, the greater the resistance to "micro-fouling" due to fine particles, scaling, crystallization or similar surface mechanisms [3]. However, if suspended particles are going to be of such a size that they may not be able to pass through the corrugations of the plate channels, then "macro-fouling" (that is, plugging) of the heat exchanger is a real concern. Here, the engineer must compare the depth of the plate groove (pressing depth) to the maximum diameter particle in the fluid stream. It is not recommended to design plate heat exchangers to handle fluids containing particles with diameters greater than 75% of the plate pressing depth. A good rule of thumb is to keep particles below 2.5 mm, although "deep groove" or "wide gap" plate designs are available from many manufacturers that can tolerate larger particles, up to 18 mm.

Fibers can be particularly problematic in plate heat exchangers since the same plate corrugations that create turbulence and high heat transfer create contact points where fibers can get trapped, building up over relatively short periods of time and plugging flow paths, requiring that the heat exchanger be opened (perhaps too frequently) for cleaning. In these cases, the engineer should consider the wide-gap plate heat exchanger, which does a good job of passing fibers and large particles and has become a workhorse in ethanol plants and other bio-based chemical manufacturing processes where fibers are a natural occurrence as a result of using biomass feedstock. However, in using wide-gap plate heat exchangers, the engineer must consider the trade-off between the ability to handle fibers and larger particles with the somewhat lower heat transfer coefficients that are a result of the lower wall shear in these more widely spaced channels.

In applications where large particles or fibers can be removed from the fluids without affecting the process, this should be done using static basket strainers or automatic backwashable strainers upstream of the plate heat exchanger.

Biological fouling, typically when natural or untreated river, lake or ocean water is used as the coolant, can be a problem for all types of heat exchangers. As in the case of shell and tubes, the foulant and the fouling mechanism must first be identified, so that an effective solution such as strainers, inline injection of biocides or regular clean-in-place (CIP) procedures can be followed.

It should be noted that while heat transfer surfaces of copper or copper-based alloys offer resistance to biological fouling, these materials are not available in corrugated plate technology.

Shell-and-tube fouling factors

Plate-heat-exchanger fouling factors can be as low as one tenth that of shell-and-tube fouling factors for the same fluids [2]. There is a danger in using a shell-and-tube fouling factor in plate-heat-exchanger designs, since, like other parallel flow path heat transfer devices, this is usually achieved in a plate heat exchanger by adding plates in parallel, thus lowering the flow rate per channel, which results in lowering the pressure drop in the heat exchanger. This lower pressure drop, in turn, lowers the wall shear stress and fluid velocity in those channels. In the author's experience, safe and proven fouling factors for plate heat exchanger design are 10% excess surface area, also expressed as 10% safety margin, equivalent to approximately (but not exactly) a cleanliness factor of 90%. To better understand fouling factors in plate heat exchangers and their relation to other terms for describing fouling, the author refers the reader to Ref. [4].

Disproportionate flow ratios

It is very common for the process engineer who commonly selects shell-and-tube heat exchangers to inadvertently design for disproportionate flow ratios between hot and cold side flows in a plate heat exchanger. This is because shell-and-tube designs require high shell-side flows to create as much turbulence as possible on the shell side. While these high shell-side flowrates allow the shell and tube to run more efficiently (at the expense of high pumping costs and water usage), using disproportionate flowrates when specifying a plate heat exchanger will immediately eliminate the advantages of high thermal efficiency and low cost that the engineer is seeking from the plate design.

The reason for this can be explained as follows: In a plate heat exchanger, two plates form a channel. So, in a 100-plate unit, there will be 50 channels for the hot side and 50 channels for the cold side. Due to the identical geometry between the hot-side flow channel and the cold-side flow channel in a plate heat exchanger — unlike in a shell and tube, where tube diameter is independent of shell diameter — a hot side flowrate of 100 gal/min with a cold side flowrate of, say, 500 gal/min will almost always require that the plate heat exchanger be designed to accommodate the flowrate and pressure drop of the 500 gal/min higher flow fluid. This leaves the lower flow side with low wall shear, low channel velocity and possibly poor fluid distribution, all resulting in heat transfer coefficients that are well below what the plate heat exchanger can achieve with more balanced flows. Again, the author's rule of thumb is to keep the volumetric flow ratios between hot and cold fluids of similar viscosities at two-to-one or less. Of course, the adverse effect of disproportionate flow ratios can be lessened by designing for an extremely high pressure drop on the high flow side or by designing for more flow paths for the high flow fluid, but this creates high pumping costs or complicated plate-pack reassembly (after opening) in the field; based on the author's experience, this approach should be avoided.

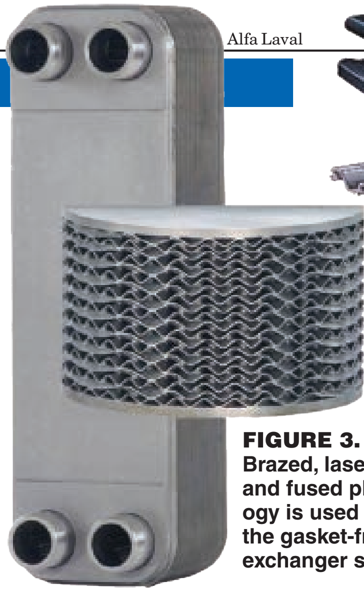

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FIGURE 3. Brazed, laser-welded and fused plate technology is used for fabricating the gasket-free plate heat exchanger shown here

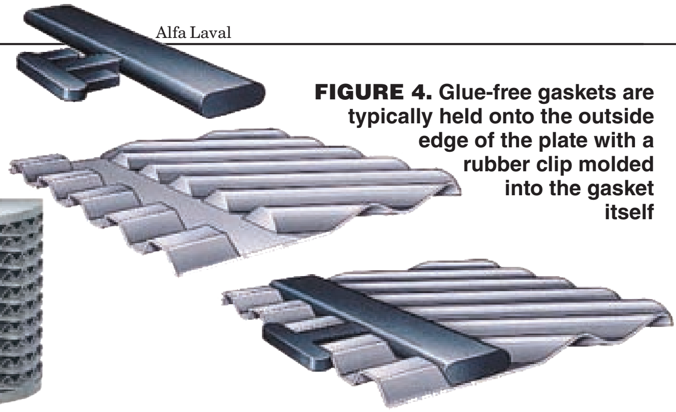

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FIGURE 4. Glue-free gaskets are typically held onto the outside edge of the plate with a rubber clip molded into the gasket itself

Optimized cooling-water flow

Responsible heat-exchanger manufacturers will almost always evaluate for their customers an alternate design in which the coolant flow is optimized to yield the most efficient — and hence the lowest cost — selection. The coolant flow that the manufacturer will come up with is usually lower than the user allowed for, thus saving water and pumping costs while creating a more efficient, balanced design. If the manufacturer does not offer an optimized alternate, the process engineer should ask for one.

Nozzle velocities

Pressure drop is the price we generally pay for heat transfer. The pressure-drop losses in any heat exchanger are made up of the entrance and exit losses as well as the losses as the fluid flows through the heat transfer passages. Too high a nozzle velocity for either the hot or cold fluid can result in wasted pressure drop getting into and out of the heat exchanger, thus reducing the useful pressure drop that contributes to high heat-transfer coefficients in the plate channels themselves. In the worst case, high nozzle velocities can cause erosion of the port in the first few plates of the plate pack (after the first few plates, the flowrate drops off as the fluid divides among the plate channels).

Typical safe velocities are not too different than those for shell and tube models, which are 5–6 m/s. In any case, be careful of pressure drops through the nozzles and the ports of a plate heat exchanger that are in excess of 35% of the total pressure drop through the heat exchanger, since that can cause maldistribution in the plate pack. In the case of maldistribution, most fluids, particularly viscous ones, may not have sufficient pressure after they enter the heat exchanger to make their way to the back of the plate pack, thus leaving some of the heat transfer area unwetted and, therefore, unused.

Solids in cooling water

In those applications where cooling water containing silt, broken sea shells or other sediment from rivers, lakes or oceans are used, the author has found it useful to incorporate two concepts in standard, gasketed plate-heat-exchanger designs, especially where these particles can be greater than 2.5 mm, which, as mentioned earlier, is the author's rule-of-thumb threshold value where straining or other solids removal methods should be considered.

Nozzle placement. Do not use one of the upper nozzles on the heat exchanger for the incoming dirty water. Instead, use one of the lower connections, forcing the particles to make a 90-deg. turn as they leave the port of each plate channel and flow upwards through the channel itself. If the fluid velocity at that point is not too high, the particle has a good chance of falling to the bottom of the port, thus staying out of the heat transfer channel where it can get trapped, causing surface fouling or plugging.

Clean-out port. In standard gasketed plate-and-frame heat exchangers where debris or particles greater than 2.5 mm may be present, consider the use of a "clean-out" port on the back cover of the plate heat exchanger. This port should be installed directly opposite the inlet port carrying the dirty fluid into the heat exchanger, so that with the exchanger off-line, vented and drained, the clean-out port can be taken off to remove any accumulated trash in the port area of the heat exchanger.

Some manufacturers now offer a basket-type port strainer that can be installed and removed easily through the clean-out port on the back cover of the heat exchanger. Although the heat exchanger must be taken out of service during the removal and cleaning of the port strainer, this task can be done without disturbing the piping or opening the heat exchanger itself.

Glued versus glue-free gaskets

Most gasketed plate-heat-exchanger manufacturers today offer gaskets in both a glued and a glue-free option. The glue-free gaskets are typically held on to the outside edge of the plate with a clip molded right into the gasket itself (Figure 4). The advantage of glue-free gaskets is that they are easily removed and replaced in the field by the operator, since there is no epoxy glue or other adhesive bond that needs to be broken in order to separate the gasket from the plate.

However, there can be a problem with the glue-free gaskets in services where the heat exchanger is going to be opened frequently for cleaning or inspection. The glue free gasket is held onto the plate by molded clips that are spaced about 12 in. apart. If not careful during disassembly, the maintenance people may allow the gasket to stretch if the portion between the clips sticks onto the neighboring plate as the plate pack is opened up. It is not possible to get such a stretched gasket back into the recessed groove it sits in.

In cases where frequent cleaning or inspection is anticipated, glued gaskets, although a bit more expensive, will allow the plate pack to be opened and closed many, many times before the gaskets need attention. In cases where frequent opening is not expected but where chemical or temperature attack of the gasket over time is a factor, glue-free gaskets should be considered since they can be quickly and easily replaced on a preventative maintenance basis.

Plate gaskets, whether glued or glue-free, should have a life of several years, unless they are in a service where they are subject to chemical or oxidative attack or are running continuously at their temperature limit. It is not at all necessary to replace plate gaskets every time the unit is opened. The author has installed plate heat exchangers in modest temperature (50–65°C), water-water service where the heat exchangers are still operating with the original gaskets after 20 years. Well-designed gaskets sit in a recessed groove, and even when the plate pack is fully tightened, the gaskets are not excessively compressed enough to become damaged.

Steam heater service

There are three points to look out for when selecting plate heat exchangers for steam heating service. First, when using plate heat exchangers in this application, high steam velocity in the port can cause erosion and noise problems. Steam velocities in excess of 100 m/s should be avoided.

Secondly, the very high heat-transfer coefficients encountered when using plate heat exchangers in steam heating service can result in small heat-transfer areas and therefore relatively small plate packs. As a result, the fluid to be heated (typically water) may experience an excessive pressure drop, and the heat exchanger will have to be oversized (typically by adding plates in parallel) to keep the water-side pressure drop within specified limits. This can add unnecessary surface area and cost.

Thirdly, the small volume in the plate channel can lead to "stalling" as the steam present in the channels rapidly condenses and forms a vacuum. Vacuum formation followed by condensate build-up can create repeated water hammer, which can damage the heat exchanger and downstream equipment. In this case, the design engineer should look for plate heat exchangers offered by some manufacturers that are specifically designed for steam heating service. These steam-heating plate exchangers have large ports, short channel lengths and deep plate-pressing depths to avoid the problems described above for standard gasketed-plate heat exchangers in steam service.

Flanged versus studded ports

There is no need to design or select plate heat exchangers with costly extended nozzles terminating in flanged connections. Almost all gasketed plate manufacturers today use lined, studded ports. The lining is usually the same material as the plate to prevent the fluid from coming in contact with the painted, carbon-steel frame. The studded-port connections present a raised-face or a flat-face ANSI bolt pattern to the user's field piping and have the advantage of no moment arm to transmit nozzle loads. Linear loads (F_x, F_y, F_z) as well as bending loads (M_x, M_y, M_z) are taken by the heavy steel frame and not by the plates. Typical allowable port loadings for the plate heat exchanger with studded ports are much greater than those for the plate heat exchanger with nozzled ports [*5*].

Summary

As with all process equipment, knowing where, why and how to install the equipment in the proper application ensures good performance with expectations fulfilled for that equipment. A solid understanding of critical areas in the design and selection of gasketed plate heat exchangers, as the author has tried to outline in this paper, is no exception to that philosophy.

Don't hesitate to ask questions of operating and maintenance personnel, who will be responsible for using the equipment, about the nature of the fluids, past experience with other types of heat exchangers in the intended service and other background that will make your installation successful. Make sure that you consult with knowledgeable manufacturers with considerable experience who can help you recognize and avert design pitfalls. ■

Edited by Gerald Ondrey

Acknowledgements

The author wishes to acknowledge Bennat Drazner, senior heat-transfer specialist at Alfa Laval, Inc. (Richmond, Va.) and also long-time member of the HTRI Technical Committee, for his proof-reading and many contributions to this paper.

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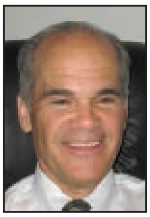

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Compact Heat Exchangers: Improving Heat Recovery

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Alfa Laval Lund AB

Iain Sinclair and **Francisco J. Alanis**
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These units offer distinct advantages over shell-and-tube heat exchangers, as quantified by the example presented here

Global warming is of major concern today. There is increasing pressure on industry to reduce both energy usage and the associated CO_2 emissions. An important and profitable action that industry can take is to recover more process energy and thus improve the efficient use of that energy. This not only reduces the cost of primary energy supply and lowers CO_2 emissions, but also provides benefits in terms of reductions in heat rejection and in the associated equipment and operating costs. While making such investments, it is also important that financial returns are maximized and that further opportunities for saving energy and reducing emissions are not missed. This article considers the use of compact heat exchangers (CHEs) for improved heat recovery, as they often achieve higher levels of savings with a better payout rate than more conventional alternatives. (for Part 1, see pp. 42–45)

Compact heat exchangers

The dominant type of heat exchanger in process plants today is the shell and tube. In many cases, it is an appropriate selection for the service required. However, because engineers are familiar with shell-and-tube varieties, they tend to select them "by default," without considering alternatives. If engineers' minds were opened to alternative technologies, such as compact heat exchangers, many heat-exchanger specifications might look different.

There are many different kinds of compact heat exchangers. The most common is the gasketed plate-and-frame heat exchanger. All CHEs use corrugated plates between the heating and cooling media. The design provides the advantages of high turbulence, high heat-transfer coefficients and high fouling resistance. High heat-transfer coefficients allow smaller heat-transfer areas compared to traditional shell-and-tube heat exchangers used for the same duty. This ultimately results in significant size reductions and weight savings as less material is needed to construct the unit. This is especially important when working with expensive corrosion-resistant metals such as titanium and Hastelloys, for example.

The gasketed plate heat exchanger is often the most efficient solution. In petrochemical and petroleum-refinery applications, however, gaskets frequently cannot be used because aggressive media result in a short lifetime for the gaskets or because a potential risk of leakage is unacceptable. In these cases, all-welded compact heat exchangers without interplate gaskets should be considered. There are several different kinds available in the market today. In the case presented in this article, a unit with overall fully counter-current flow is used to enable the required heat recovery, while also allowing mechanical cleaning. In addition, all welds are accessible for repair purposes if this type of maintenance becomes necessary during the life of the exchanger.

When to use CHEs

CHEs can be used in most industrial applications as long as design temperature and pressure are within the accepted range, which normally is up to 450°C and 40 barg. CHEs are often the best alternative when the application allows gasketed or fully welded plate heat exchangers, when a high-grade, expensive construction material is required for the heat exchanger, when plot space is a problem or when enhanced energy recovery is important.

When the application allows shell-and-tube heat exchangers to be manufactured completely of carbon steel, such design normally provides the most cost-efficient solution. However, even in those cases, CHEs can have advantages, such as space savings, superior heat recovery and a higher resistance to fouling, which make them well worth considering.

If you do not know if your application can be handled by compact heat exchangers, ask a vendor. Suppliers are normally willing to give you a quick budget quote when their equipment is appropriate for your application so that you can compare solutions and determine which would be best for you. As part of the vendor enquiry, design options for enhanced heat recovery can be quantified and additional energy saving benefits and capital cost changes can be defined. At this stage, in some circumstances, it may be favorable to respecify the heat-exchanger performance requirements to take advantage of the improved heat recovery that can be achieved with a CHE.

CHE versus shell-and-tube

All-welded CHEs consist of plates that are welded together (Figure 1). Among the many models available on the market today, all have one thing in common: they do not have inter-plate

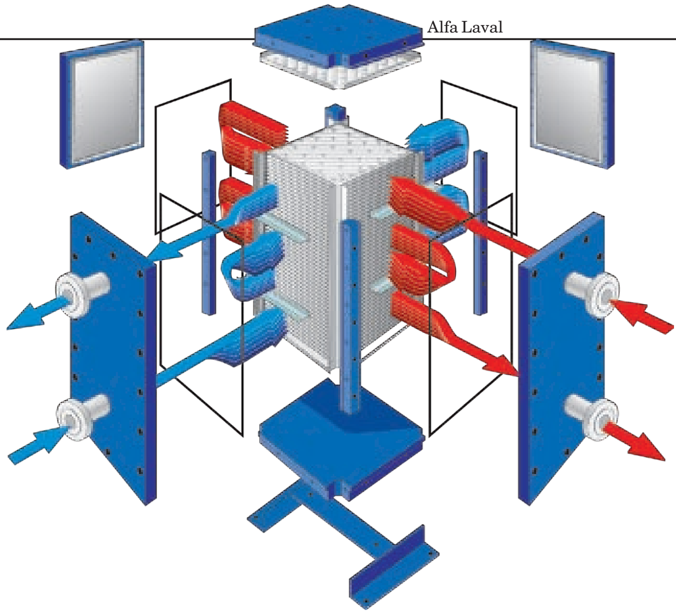

FIGURE 1. All-welded compact heat exchangers are very compact compared to shell-and-tube heat exchangers

TABLE 1. REQUIRED MINIMUM PERFORMANCE OF REPLACEMENT HEAT EXCHANGER				
Process fluid		**T in, °C**	**T out, °C**	**Duty, kW**
Hot side	Quench water	88.6	58.9	10,000
Cold side	Polished water	18.0	77.0	

gaskets. This feature is what makes them suitable for processes involving aggressive media or high temperatures where gaskets cannot be used.

On the other hand, some of these all-welded heat exchangers are sealed and cannot be opened for inspection and mechanical cleaning. Others can be opened, allowing the entire heat-transfer area and all welds to be reached, cleaned and repaired if necessary.

Because all-welded heat-exchanger plates cannot be pressed in carbon steel, plate packs are available only in stainless steel or higher-grade metals. The cost of an all-welded compact heat exchanger is higher than that of a gasketed plate heat exchanger. Nevertheless, in cases where gaskets cannot be used, all-welded compact plate heat exchangers are still often a strong alternative to shell-and-tube heat exchangers.

The most-efficient, compact, plate-heat-exchanger designs have counter-current flows or an "overall counter-current flow" created by multi-pass arrangements on both the hot and cold sides. Such units can be designed to work with crossing temperatures and with temperature approaches (the difference between the outlet temperature of one stream and the inlet temperature of the other stream) as close as 3°C.

As mentioned before, all-welded CHEs are very compact in comparison to shell-and-tube heat exchangers. CHEs have this advantage due to their higher heat-transfer coefficient and the resulting much smaller heat-transfer area. The units typically occupy only a fraction of the space needed for a shell-and-tube exchanger. Space savings are accompanied by savings on foundations and constructional steel work, and so on. The space needed for maintenance is also much smaller as no tube-bundle access and withdrawal space is required.

Due to the short path through the heat exchanger, the pressure drop can be kept relatively low, although this depends on the number of passes and the phase of the fluid. For most liquid-to-liquid duties, a 70–100 kPa pressure drop is normal, while for a two-phase flow, the pressure drop can be as low as 2–5 kPa.

Regarding heat recovery, the main advantage of the CHE is that it operates efficiently with crossing temperatures and close temperature approaches. This makes it possible to transfer more heat from one stream to another or to use a heating medium that is just a few degrees warmer than the cold medium.

There are two main reasons why all-welded CHEs are more thermally efficient than shell-and-tube heat exchangers:

- All-welded CHEs have high heat-transfer coefficients. This is due to the high turbulence created in the corrugated plate channels. The high turbulence results in thin laminar films on the surface of the heat-transfer area. These have a much lower resistance to heat transfer compared to the thicker film found in a shell-and-tube heat exchanger
- Counter-current flows (or overall counter-current flows) can be achieved in all-welded compact heat exchangers. This means that a single heat exchanger, operating with crossing temperatures and a close temperature approach can replace several shell-and-tube heat exchangers placed in a serial one-pass arrangement, to emulate the counter-current flow of the compact heat exchanger design

As a result, CHEs may be more cost-effective and may present a more practical alternative to shell-and-tube heat exchangers. In addition to the financial benefits, space savings can also be an important factor for upgrading existing plants as well as for new plant designs.

The advantages of CHEs over shell-and-tube heat exchangers will become clear with the following example taken from an actual application.

A real application example

In a recent feasibility study for improving the energy efficiency of a European ethylene plant, a number of opportunities to increase the export of high-pressure (HP) steam to the site's utility system were identified. The changes included unloading the refrigerant compressors and increasing heat recovery from the quench water loop.

One such opportunity was the replacement of an existing quench water/polished water shell-and-tube heat exchanger that was limiting heat recovery. From an energy point of view, it was desirable to maximize heat transfer between these streams. This would reduce both the low-pressure (LP) steam required for boiler feed water (BFW) deaeration (due to an increase in deaerator BFW feed temperature) and would also reduce the heat-duty load on the cooling water tower (a site bottleneck), due to a reduction in quench water cooling against cooling water.

The required minimum performance of the replacement heat exchanger is detailed in Table 1.

A preliminary assessment of the suitability of a shell-and-tube heat

TABLE 2. A SUMMARY OF ALTERNATIVE HEAT-EXCHANGER DESIGNS										
Case	Type		# of units	Heat duty, kW	LMTD* corrected, °C	Overall heat-transfer coefficient, W/(m²K)	ΔP hot side, kPa	ΔP cold side, kPa	Heat transfer area, m²	Purchase cost, %
Base	Shell-and-tube	BEM	2	10,000	23.3	921	7	17	468	100
Case 1	Compact HE	CPK75-202	1	10,000	23.3	3,373	50	97	129	99.6
Case 2	Compact HE	CPK75-252	1	10,810	15.9	3,667	73	64	161	111.6
Case 3a	Compact HE	CPK75-302	1	11,310	14.8	3,993	53	104	193	125.5
Case 3b	Shell-and-tube	BEM	2	11,310	14.9	879	9	22	864	169.1

* Logarithmic mean temperature difference

TABLE 3. MONETARY SAVING COMPARISON OF COMPACT HEAT EXCHANGERS VERSUS SHELL-AND-TUBE HEAT EXCHANGERS									
Case	Type		# of units	Heat duty kW	LP steam saving		CO_2 credits		Total Million €/yr
					m.t./hr	Million €/yr	m.t./hr	Million €/yr	
Base	Shell-and-tube	BEM	2	10,000	11.7	1.38	3.0	0.50	1.88
Case 1	Compact HE	CPK75-202	1	10,000	11.7	1.38	3-0	0.50	1.88
Case 2	Compact HE	CPK75-252	1	10,810	13.0	1.53	3.2	0.54	2.08
Case 3a	Compact HE	CPK75-302	1	11,310	13.8	1.63	3.4	0.57	2.20
Case 3b	Shell-and-tube	BEM	2	11,310	13.8	1.63	3.4	0.57	2.20

exchanger indicated that two shells in series (468 m²) would be an economical compromise, achieving a heat recovery of 10 MW with an 11.6˚C temperature approach at the hot end.

At this stage, a compact heat exchanger was compared with the shell-and-tube alternative. An all-welded rather than a gasketed plate heat exchanger was chosen because of limited gasket lifetime when there is contact with quench water. Additionally, because of potential quench-water side fouling, an all-welded heat exchanger that could be mechanically cleaned was preferred.

As mentioned previously, selecting an all-welded CHE instead of a shell-and-tube heat exchanger makes it possible to further increase energy savings, by reducing temperature approach. In this case, the hot-end temperature approach determines the duty and thus the size and design of the heat exchanger. For a compact heat exchanger with counter-current flows it is normally possible (and economical) to decrease the temperature approach to 3–5°C. To take advantage of this potential, various improved heat recovery designs were investigated.

A summary of alternative heat-exchanger designs is shown in Table 2. There, it can be seen that the heat-transfer coefficient for the compact heat exchanger is much higher than for the shell-and-tube heat exchanger. This is due to the highly turbulent flow created by the corrugated plates in the CHE. As a result, a much smaller heat-transfer area is required. When comparing the cost of the all-welded CHE and the shell-and-tube heat exchanger, it should be remembered that the plate material in the CHE is stainless steel (ANSI 316L), while carbon steel is used in the shell-and-tube heat exchanger.

It should also be noted that the pressure drop is higher for the compact heat exchanger than for the shell-and-tube heat exchanger. This will, of course, increase the fluid-pumping cost. A true comparison must take these costs into account. However, since the pumping costs are usually small when compared to the overall energy savings achieved, the financial outcome for this example is unlikely to change.

The installation cost of shell-and-tube heat exchangers will be higher, especially for a multi-shell design. In this case, the total installed cost comparison would therefore be significantly more favorable for compact heat exchangers than the purchase cost comparison given above.

For the heat exchangers considered in this example, Table 3 shows how energy and emissions reductions improve as the cold-side outlet temperature is increased to reduce the hot-end temperature approach from 11.6°C to 3.9˚C. To achieve this, 50% more compact heat exchanger surface area is required. This increases the cost of the unit by only 26%; however, on the other hand, two shell-and-tube heat exchangers in series would be required to achieve the same performance, which would require 85% more heat-transfer area, at a 69% higher cost.

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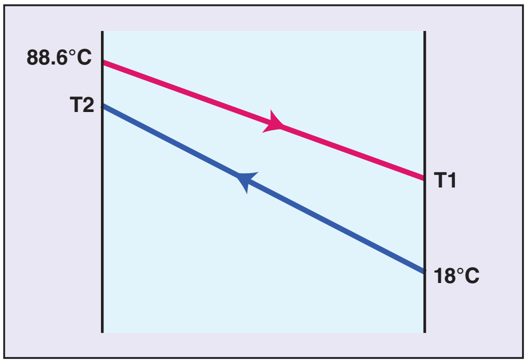

FIGURE 2. For a compact heat exchanger with counter-current flow, as shown in Figure 3, it is normally possible to decrease the temperature approach to 3–5°C

FIGURE 3. Counter-current flows can be achieved in all-welded compact heat exchangers. This means that a single heat exchanger, operating with crossing temperatures and close temperature approach, can replace several shell-and-tube heat exchangers placed in a serial, one-pass arrangement

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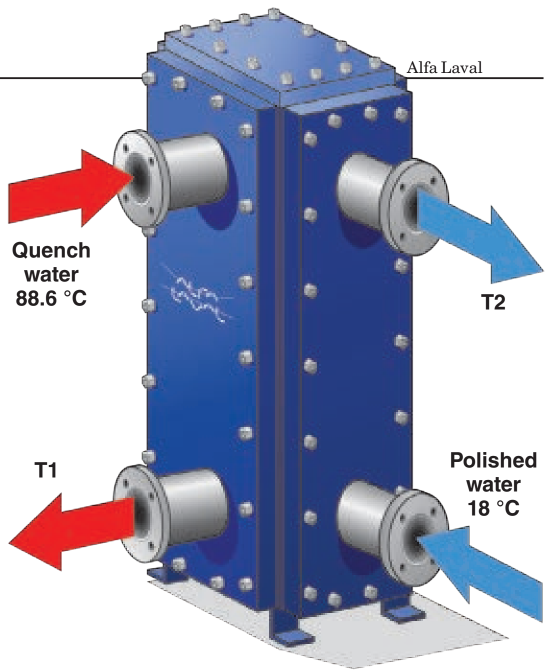

All design options offer reasonable monetary savings. Heat exchanger selection is therefore primarily driven by capital cost. A compact heat exchanger design allows improved heat recovery with only a marginally longer payback time, and therefore, is a strong candidate for selection.

The all-welded compact heat exchanger in Case 3a provides maximum energy savings and CO_2 credits at a lower size, cost and payback time than the corresponding shell-and-tube heat exchanger in Case 3b. With 17% additional monetary saving, the payback time for the compact heat exchanger is only 8% longer, whilst the payback time for the shell-and–tube heat exchanger design is 44% longer.

The following two points should also be noted:

- The installation cost of the all-welded CHE should be lower than for a shell-and-tube, especially when the shell-and-tube design is a multi-shell arrangement, as in this comparrison
- All-welded CHEs often provide better lifecycle performance and lower maintenance costs than shell-and-tube designs, because there is less fouling. Less fouling means less-frequent cleaning, which in turn reduces downtime (or at least the maintenance work). Compact all-welded heat exchangers are also very easy to clean. Their panels can simply be removed to allow mechanical cleaning with high-pressure water. Shell-and-tube heat exchangers, on the other hand, take longer to clean

Final remarks

There is increasing pressure on industry today to reduce CO_2 emissions. Reducing energy use by improving process heat recovery, is an effective way for companies to respond to this pressure.

Reducing energy use lowers costs for primary energy supply and thus reduces operating costs. Also if primary energy supply is reduced, heat rejection must also reduce. Overall, the capital investment cost for all heat transfer equipment is often lower.

It is our experience that opportunities for improved heat recovery and reduced CO_2 emissions exist in most chemical process industries (CPI) plants, and that some of these opportunities can be realized with short payback times. This allows companies to contribute to CO_2 reduction initiatives and to reap financial benefits.

Effective feasibility studies for reducing energy use should follow a systematic approach and involve equipment vendors, to ensure that all potential opportunities are fully exploited.

Finally, all-welded compact heat exchangers can often improve heat recovery, while achieving greater savings with a better payback rate than more conventional alternatives such as shell-and-tube heat exchangers. ■

Edited by Gerald Ondrey

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Eye-and-Face Personal Protective Equipment


Gateway Safety

FIGURE 1. Safety glasses help shield eyes from impact hazards

Protecting the eyes and face in the workplace is imperative to preventing the estimated 10–20% of work-related eye injuries that result in temporary or permanent vision loss

Victor J. D'Amato
Atrium Environmental Health and Safety Services

Eye injuries of all types occur at a rate of more than 2,000 per day in the U.S., and half of those occur in the workplace. In 2006, the U.S. Bureau of Labor Statistics (BLS) reported over 52,000 workplace injuries to the eyes and face, and approximately 70% of those were eye injuries [*1*]. The need to protect the face and eyes in the workplace is clear.

Implementing an eye-and-face protection program is important for several reasons. One is compliance. Between October 2006 and September 2007, more than 450 citations resulted in more than $215,000 in fines and penalties to manufacturers for failure to comply with the U.S. Occupational Safety & Health Administration (OSHA) standard for eye and face protection [*2*].

Another reason is the cost of eye and face injuries. The financial cost of these injuries is enormous and can range from $300 to $3,000 per case. More than $300 million per year is lost in production time, medical expenses, and workers' compensation according to OSHA. The return on investment for implementing an eye-and-face safety program is huge as its cost is relatively inexpensive compared to the potential expense of an injury. But, no dollar figure can adequately reflect the personal toll these accidents take on injured workers. Prevent Blindness America estimates that 10–20% of work-related eye injuries result in temporary or permanent vision loss.

This article outlines the basics of eye-and-face protection programs for plant operations, including key compliance requirements and practical information for personal protective equipment (PPE) selection.

The causes of injuries

Most impacts to the face come from flying objects, usually particulate matter. When a particle hits the face it might cause a cut or scratch, and the skin will repair itself over time given proper medical attention. If the particle hits the eye, it causes direct damage, and it is far more difficult for the eye to repair itself.

BLS reports that of the nearly 36,000 injuries to workers' eyes in 2006, nearly 70% resulted from contact with objects like flying particles, falling objects or sparks striking the eye. Contact with chemicals was responsible for the remaining 30% of eye injuries.

OSHA compliance

OSHA defines minimum requirements for workplace PPE in Subpart I of the Occupational Safety and Health Standards for general industry employers (29 CFR 1910), which include the chemical process industries (CPI). The general requirements of this standard include that employers select PPE for their employees based on the hazards present in the workplace, and that employers train employees on the proper use and limitations of the PPE selected for use. In November 2007, OSHA updated the standard to specifically require employers to pay for the PPE required under the standard, with some limited exceptions [*3*].

The OSHA Eye and Face Protection Standard (29 CFR 1910.133) was established specifically to protect employees from eye and face hazards in the workplace. To comply with this standard, employers must ensure the following:

1. Employees who may be exposed to eye or face hazards from flying particles, molten metal, liquid chemicals, acids, caustic gases, vapors or potentially injurious light radiation use appropriate eye or face protection.
2. Employees who may be exposed to a hazard from flying objects use eye protection that provides side protection.
3. Employees who require prescription lenses while engaged in operations that involve eye hazards wear eye protection that incorporates the prescription in

TABLE 1. HAZARD ASSESSMENT		
Hazard type	**Examples of hazard**	**Common related tasks**
Impact	Flying objects, such as large chips, fragments, particles, sand and dirt	Chipping, grinding, machining, masonry work, wood working, sawing, drilling, chiseling, powered fastening, riveting and sanding
Heat	Anything emitting extreme heat	Furnace operations, pouring, casting, hot dipping and welding
Chemicals	Splash, fumes, vapors and irritating mists	Acid and chemical handling, degreasing, plating and working with blood
Dust	Harmful dust	Woodworking, buffing and generally dusty conditions
Optical radiation	Radiant energy, glare and intense light	Welding, torch-cutting, brazing, soldering and laser work

Source: U.S. Dept. of Labor, Occupational Safety & Health Administration (OSHA), Eye and Face Protection eTool, http://www.osha.gov/SLTC/etools/eyeandface/ppe/selection.html

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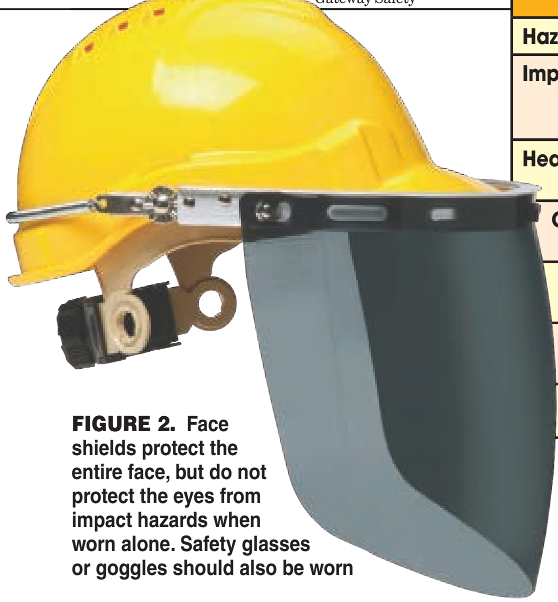

FIGURE 2. Face shields protect the entire face, but do not protect the eyes from impact hazards when worn alone. Safety glasses or goggles should also be worn

its design, or that they wear eye protection that can be worn over the prescription lenses without disturbing the proper position of the prescription lenses or the protective lenses.

4. Eye-and-face personal protective equipment is distinctly marked so that the manufacturer is clearly identified.
5. Employees who may be exposed to injurious light radiation during work process, such as welding, thermal cutting, brazing, torch soldering, and using lasers, use eye protection equipped with filter lenses that have a shade number appropriate for the work being performed.

IMPLEMENTATION

Implementing a practical, effective PPE program includes the following straightforward steps, which are described in more detail below.

1. Assess the workplace for hazards.
2. Select PPE based on these hazards.
3. Train workers on proper PPE use.
4. Determine how prompt emergency care will be provided in the event of an accident.

Hazard assessment

OSHA provides guidance on conducting hazard assessments, which are summarized as follows [*4*].

1. The first step in the hazard assessment for eye and face protection is to walk through your facility and identify the potential hazards that can injure the eyes or face. Hazards should be assessed by occupation or trade, work area and work activity.
2. Identify the sources of the hazards. Talk to employees as they know best about their trades, work areas and processes. Consider all possible hazards, even those that seem minor or unlikely. Some examples of eye and face hazards and typical sources are summarized in Table 1.
3. Organize the data collected. Develop a table or spreadsheet listing the occupations, work areas, and processes you identify, the hazards identified in each category, and the sources of the hazards.
4. Analyze your data, considering the probability and severity of each hazard. Keep in mind that multiple hazards and sources may be present. This will help in deciding which PPE is appropriate.
5. Certify your assessment. OSHA requires that every employer verify its assessment, identifying the areas assessed, who performed the assessment, and the dates it was performed.
6. Review and update your assessment on a routine basis, or if changes in the workplace or processes are planned.

PPE selection

The American National Standards Institute (ANSI) standard for eye and face protection (Z87.1) sets forth criteria related to the description, general requirements, testing, marking, selection, care and use of eye and face PPE in the workplace. The 2003 edition specifies requirements for safety glasses, safety goggles, face shields and full-face and hooded respirators. This ANSI standard is revised and updated routinely to reflect current technologies and the current state of practice. While most PPE manufacturers have adopted the 2003 edition of the standard in new products, eye and face PPE currently being used may have been manufactured to meet earlier editions of ANSI Z87.1. OSHA requires that eye and face PPE purchased after July 1994 be manufactured to meet the 1989 edition of ANSI Z87.1.

Eye and face PPE that meets the criteria specified in ANSI Z87.1 must be marked with a manufacturer's unique marking and the "Z87" marking. Special purpose lenses and shaded lenses must also be marked indicating the purpose and shade. Eye and face PPE must be selected based on the hazards identified in the hazard assessment. Some examples of the types of protection available for hazards are summarized in the next sections.

Ultimately, the eye and face protection must be comfortable to wear and not interfere with the employee's work. Poor-fitting PPE will not afford the necessary protection, may be uncomfortable to wear, and may not get used. Since eye-and-face protection devices can come in different sizes, care should be taken to ensure that the right size is selected.

Impact hazards. Safety spectacles (Figure 1) are intended to shield the wearer's eyes from impact hazards, such as flying fragments, objects, large chips, and particles. Workers are required to use eye safety spectacles with side shields when there is a hazard from flying objects. Non side-shield spectacles are not acceptable eye protection for impact hazards. The selection of safety glasses is almost infinite as a host of manufacturers have stepped up to meet employee demand.

Safety goggles are also intended to shield the wearer's eyes from impact hazards. Goggles fit the face immediately surrounding the eyes and form a protective seal around the eyes. This prevents objects from entering under or around the goggles.

Face shields (Figure 2) are intended to protect the entire face or portions of it, but they do not protect employees' eyes from impact hazards when worn alone. Face shields should be used in combination with safety spectacles or goggles for additional protection. Face-shield windows are made of varying types of transparent materials and in varying thicknesses, both of which should be considered when selecting face shields for specific tasks. Window and headgear devices are available in various combinations to be compatible with other PPE, such as hardhats.

Welding shields (Figure 3) provide eye and face protection from flying particulate matter during welding, thermal cutting and other hot-work activities. These shields are typically equipped with shaded lenses that provide protection from optical radiation.

Heat hazards. Working with heat requires goggles or safety spectacles with special-purpose lenses and side shields. However, many heat-hazard exposures require the use of a face shield in addition to safety spectacles or goggles. When selecting PPE, consider the source and intensity of the heat and the type of splashes that may occur in the workplace.

Chemical hazards. Safety goggles (Figure 4) protect the eyes, eye sockets, and the facial area immediately surrounding the eyes from a variety of chemical hazards. The protective seal formed around the eyes is especially important when working with or around liquids that may splash, spray or mist. Several kinds of cover-type goggles are available: direct vented, indirectly vented or non-vented. It's important to select the right type. Vented goggles, for example, may be less effective in protecting the eyes from splashes and respiratory aerosols than non-vented or indirectly vented goggles.

Face shields are intended to protect the entire face from a variety of chemical hazards, particularly when pouring chemicals or where splashes may occur. Face shields are considered secondary protection and must be used in addition to safety goggles to provide adequate protection.

Dust hazards. Working in a dusty environment can cause eye injuries and presents additional hazards to contact lens wearers. Safety goggles should be worn when dust is present. Safety goggles are the only effective type of eye protection from nuisance dust.

Optical radiation hazards. Welding, thermal cutting, brazing, laser work and similar operations create intense concentrations of heat, ultraviolet, infrared, and reflected-light radiation. Some of these activities can produce optical radiation intensities greater than those experienced when looking directly at the sun. Unprotected exposure may result in eye injuries including retinal burns, cataracts, and permanent blindness. Many lasers produce invisible ultraviolet, and other forms of non-ionizing radiation.

The OSHA standard (29 CFR 1010.133) includes a table that lists the minimum shade requirements for eye protection during industrial processes that generate optical radiation. The selection of eye protection for lasers should depend on the lasers in use and the operating conditions, and should be consistent with the laser manufacturer's specifications.

PPE and prescription lenses. If employees wear reading glasses with basic magnification, ANSI-approved safety glasses and goggles with reading magnifiers in the lenses are an option. It's also possible to buy prescription safety glasses and goggles that are compliant with the ANSI standard. ANSI-compliant goggles and safety glasses are also available to fit over prescription glasses; but, they can be uncomfortable and less likely to be worn.

Wearing contact lenses under some circumstances provides workers with a greater choice of eye and face protection and better visual acuity. However, the risk of injury to the eye from chemical exposure is unknown for contact lens wearers compared with non-wearers working with chemicals. It is important to note that contact lenses are not eye protective devices, and wearing them does not reduce the requirement for eye and face protection.

In June 2005, the U.S. National Institute for Occupational Safety and Health (NIOSH) issued a Current Intelligence Bulletin (CIB) on the use of contact lenses in chemical environments. In this CIB, NIOSH recommends that workers be permitted to wear contact lenses when handling hazardous chemicals provided that certain safety guidelines are followed and that contact lenses are not banned by regulation or contraindicated by medical or industrial hygiene recommendations. OSHA recommends against contact-lens use when working with certain chemicals, including acrylonitrile, methylene chloride, 1,2 dibromo-3-chloropropane, ethylene oxide and methylene dianiline.

The NIOSH recommendations are specifically intended for work with chemical hazards, and do not address hazards from heat, radiation, or high-dust or high-particulate environments [5].

Usable life of PPE. All PPE has a usable lifespan. Most manufacturers recommend how frequently eye-and-face protection equipment should be replaced. If the PPE becomes damaged or distorted, it must be replaced to work properly. As far as the usable life of a product, a good rule of thumb is if your safety glasses are more than five years old, they may not be compliant with the latest ANSI standards, so you should get a new pair.

FIGURE 3. Welding shields are typically equipped with shaded lenses to protect from optical radiation

SUMMARY OF NIOSH RECOMMENDED SAFETY GUIDELINES FOR CONTACT LENS USE IN CHEMICAL ENVIRONMENTS

1. Conduct an eye-injury hazard evaluation* in the workplace that includes an assessment of the following:
   - Chemical exposures
   - Contact lens use
   - Appropriate eye and face protection for contact lens wearers
2. Provide suitable eye and face protection for all workers exposed to eye injury hazards, regardless of contact lens wear.
3. Establish a written policy documenting general safety requirements for wearing contact lenses, including the eye and face protection required and any contact lens wear restrictions by work location or task.
4. Comply with current OSHA regulations on contact lens wear and eye and face protection.
5. Notify workers and visitors about any defined areas where contact lenses are restricted.
6. Identify to supervisors all contact lens wearers working in chemical environments to ensure that the proper hazard assessment is completed and the proper eye protection and first aid equipment are available.
7. Train medical and first aid personnel in the removal of contact lenses and have the appropriate equipment available.
8. In the event of a chemical exposure, begin eye irrigation immediately and remove contact lenses as soon as practical. Do not delay irrigation while waiting for contact lens removal.
9. Instruct workers who wear contact lenses to remove the lenses at the first signs of eye redness or irritation.
10. Evaluate restrictions on contact lens wear on a case-by-case basis, taking into account the visual requirements of individual workers wearing contact lenses as recommended by a qualified ophthalmologist or optometrist.

* NIOSH recommends that eye injury hazard evaluations be conducted by competent, qualified persons such as certified industrial hygienists, certified safety professionals, or toxicologists. Information from the hazard evaluation should be provided to the examining occupational health nurse or occupational medicine physician.

Source: Contact Lens Use in a Chemical Environment, Current Intelligence Bulletin 59, NIOSH Publication No. 2005-139: June 2005


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FIGURE 4. Safety goggles form a protective seal around the eyes

Employee training

BLS reports that workers injured while not wearing protective eyewear often say they believed it was not required by the situation. Even though the vast majority of employers furnish eye protection to employees at no cost, about 40% of workers report they receive no information on where and what kind of eyewear should be used.

OSHA requires that all employees who use PPE for protection against workplace hazards be trained in when and how to use their PPE. This training must include the following:

1. A summary of the occupations, work areas or tasks where eye and face protection is necessary.
2. What types of eye and face protection are necessary for each occupation, work area or task.
3. How the eye and face protection is put on, taken off, adjusted and worn to be effective.
4. The limitations of the eye and face protection used.
5. The manufacturer's recommendations on the proper care, maintenance, useful life and disposal of eye and face protection devices.

Training must be conducted prior to an employee's assignment to the work area or task where the hazards may be present, and at the time when the eye and face protection is issued. There is no annual requirement for retraining; the onus of ensuring that employees understand when and how to use their eye and face protection is on the employer. OSHA does state that when employees are found wearing PPE improperly or not at all, they need to be retrained.

Emergency care

OSHA mandates that if a hazard exists, a means for flushing the eye must be provided. The eye-and-face protection program should include considerations for emergency eyewash stations that provide a full 15-min flush. There is an ANSI standard (Z358) for eyewash stations. In the field, eyewash bottles can be on hand for interim assistance until an eyewash station can be reached. There are also portable eyewash stations available that can dispense water for 15 minutes.

Resources

OSHA has an excellent Eye and Face Protection eTool on its website (http://www.osha.gov/SLTC/etools/eyeandface/ppe/selection.html) that can assist with hazard assessments, provides information about selecting PPE and summarizes specific OSHA requirements. The OSHA guidelines in Ref. 4 also include a useful PPE selection guide.

The American Industrial Hygiene Association website (www.aiha.org) offers more information on occupational health and safety topics including a list of industrial hygiene consultants who specialize in safety issues. ■

Edited by Dorothy Lozowski

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Flow Measurement & Control

Sensirion

Fluid Components International

Emerson Process Management

This unit offers measurements for low flows in the milliliter range

The SLQ-HC60 (photo) fills a gap in the existing range of products for precise measurement in the low flowrate range, below 100 mL/min. This water-resistant meter operates without moving parts and can detect bubbles in the microliter range as well. The unit requires a supply voltage of 24 V and provides a 0–10-V analog output signal. The simple, straight flow channel of the SLQ-HC60 can be connected to 1/8-in. or 3-mm plastic hoses via threaded couples. — *Sensirion AG, Staefa, Switzerland*
www.sensirion.com

Use this thickness gauge for ultrasonic clamp-on flowmeters

Since even the smallest miscalculation of the pipe-wall thickness can have a major impact on a clamp-on flowmeter's accuracy, a pipe thickness gauge needs to be extremely accurate. The Sitrans F US thickness gauge operates at a 5-MHz frequency enabling it to measure even the smallest pipe thickness. Although the thickness gauge was originally designed to increase the accuracy of clamp-on flowmeters, it can be used to measure the thickness of any pipe wall from 0.1 to 200 mm (0.03 to 7.9 in.). It works on various metallic and non-metallic materials, such as steel, aluminum, titanium, plastics and ceramics. — *Siemens Energy & Automation, Alpharetta, Ga.*
www.sea.siemens.com

Remote mass flowmeter for small lines in hazardous areas

Engineers who need to measure process gas, fuel gas or waste gases as well as air in small-line sizes will find the ST75 Flow Meter (photo) is now available in a remote mountable configuration for applications in hazardous areas or hard-to-reach places. Designed for line sizes from 0.25 to 2.0 in. with a flow range of 0.01 to 559 scfm, the ST75 provides three outputs: the mass flowrate, totalized flow and media temperature. Its flow element has a no-moving parts design that employs platinum RTD sensors embedded in mass thermowells with microprocessor electronics calibrated to laboratory standards for a wide range of gases including: natural gas, methane, nitrogen, carbon dioxide, argon, all inert gases, compressed air and more. — *Fluid Components International, San Marcos, Calif.*
www.fluidcomponents.com

A new technology platform for flow computers is introduced

The FloBossT107 flow manager (photo) is the newest addition to this company's FloBoss family of natural gas and liquids flow computers. In addition to a new highly scalable technology platform, the FloBoss 107 also features new, dynamic configuration software and an LCD touchpad to enhance ease of use. In addition to its many new features, the FloBoss 107 retains all of the tried and true features including highly accurate measurement calculations, extensive data archival capabilities, broad communications support, low power consumption, PID loop control, logic/sequencing control and environmental ruggedness. The flow manager supports up to four meter runs using multi-variable sensors. — *Emerson Process Management, St. Louis, Mo.*
www.emersonprocess.com

Measure mass or volumetric energy flow with this meter

The DIVA compact steam flowmeter is offered for general metering applications as well as fiscal metering, product costing and efficiency monitoring. With automatic compensation for changes in steam density, the unit provides 4–20-mA and pulsed outputs proportional to mass or energy flow, as well as realtime displays of steam pressure, temperature, flowrate and total flow in both English and SI units. Featuring a wafer design, the unit can be mounted in either vertical or horizontal lines and requires straight line runs of only six pipe diameters upstream and three downstream. These factors help make the DIVA flowmeter easily installed where other meters, such as orifice plates or vortex meters, cannot be applied. — *Spirax Sarco, Inc., Bythewood, S.C.*
www.spiraxsarco.com/us

This Coriolis mass flowmeter is corrosion-resistant

The tantalum version of the Optimass 7300 Coriolis mass flowmeter (photo, p.53) was launched to handle the highly aggressive and corrosive fluids found in the CPI (chemical process industries). The twin, bent-tube design of some Coriolis meters has made the use of tantalum expensive.

Universal Flow Monitors

Krohne

Swagelok

This was due to the flange, flow splitter and measuring tubes all being made from tantalum. With the advent of the single, straight-tube design, the material looked more attractive due to the fact that only the measuring tube and raised face of the process flange needs to be made from tantalum. To overcome tensile-strength issues, this company uses tantalum Ta10W, which is made up of 10% tungsten and 90% tantalum. The manufacturer has found this to be an ideal material for use in the Optimass 7300, as tungsten provides the additional tensile strength required to handle the stresses associated with straight-tube technology. — *Krohne, Inc., Peabody, Mass.*
www.krohne.com

Custom calibrate these variable area flowmeters

Used to measure liquid and gas flowrates by means of a tapered tube and float, these variable area flowmeters (photo) feature individually calibrated scales and a 10:1 turndown ratio. All units are factory calibrated and marked to indicate the specific media, flow range, and accuracy class. In addition, they can be calibrated and marked to specific applications. The G Series models feature glass measuring tubes, which enable direct view of the process reading and flow at the meter. For use in difficult operating conditions where pressure or temperature is a factor, the M Series models are equipped with metal measuring tubes and mechanical or electronic displays. NPT and flange-end connections are available in sizes from 1/8 to 1¼ in. Available options include high/low flow indicators, transistor relays and 4–20-mA analog outputs. — *Swagelok Co., Solon, Ohio*
www.swagelok.com

These transmitters are for higher temperature water and corrosives

Made of chlorinated polyvinyl chloride (CPVC), these flowrate transmitters offer heat resistance in processing corrosive fluids, water, brine and low-viscosity fluids in water treatment, chemical and desalination applications. The P420 Series (photo) offers a wide selection of cost-effective plastic flowmeters without moving parts that can stick, bind or coat when processing water or corrosives. P420 vortex-shedding meters with CPVC body, sensor and bluff can transmit hot water or other fluids with maximum operating temperature of 180°F, compared to a maximum of 140°F with PVC units. Five pipe diameters from 0.5 to 2 in. are offered, providing flowrates from 12 to 200 gal/min. — *Universal Flow Monitors, Inc., Hazel Park, Mich.*
www.flowmeters.com

This bolt-on heating jacket encloses visual flow indicators

Composed of "clamshell" halves consisting of a carbon or stainless-steel pressure chamber within an aluminum casting, this heating jacket allows direct observation of high-temperature or temperature-sensitive process fluids without creating a cold spot on temperature-controlled process piping. This new jacket fits directly on the manufacturer's standard view-thru visual flow indicator, exposing only the small area of the indicator's viewing port to ambient temperature. Tested in accordance with the ASME Boiler and Pressure Vessel Code, Sec. VIII, Div. 1 standards, the jackets are capable of maintaining operating temperatures up to 750°F. Heating media ranges from hot water to steam to hot oil and vapors. — *LJ Star Inc., Twinsburg, Ohio*
www.ljstar.com

Low-cost injection-molded flowmeters are available

Manufactured from polysulfone, a heat-resistant thermoplastic, these flowmeters provide good chemical resistance. For easy installation, Quik Loc connectors couple the meter body to the pipe connectors at the end of the flowmeter. Features include easy-to-read, direct-reading dual scales available in overlapping flow ranges for water or air. Models are available with 316 stainless-steel, PTFE or PVC floats. — *Dakota Instruments, Inc., Orangeburg, N.Y.*
www.dakotainstruments.com ■

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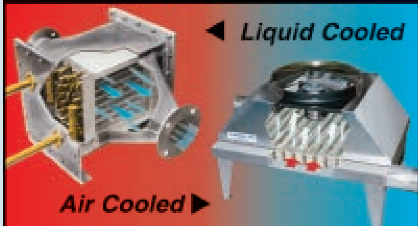

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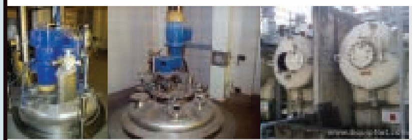

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12 Stone, Clay, Glass, Ceramics
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17 Energy incl. Co-generation
18 Other____________

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20 Corporate Management
21 Plant Operations incl. Maintenance
22 Engineering
23 Research & Development
24 Safety & Environmental
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EMPLOYEE SIZE
28 Less than 10 Employees
29 10 to 49 Employees
30 50 to 99 Employees
31 100 to 249 Employees
32 250 to 499 Employees
33 500 to 999 Employees
34 1,000 or more Employees

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45 Motors, Motor Controls
46 Piping, Tubing, Fittings
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48 Pumps
49 Safety Equipment & Services
50 Size Reduction & Agglomeration Equipment
51 Solids Handling Equipment
52 Tanks, Vessels, Reactors
53 Valves
54 Engineering Computers/Software/Peripherals
55 Water Treatment Chemicals & Equipment
56 Hazardous Waste Management Systems
57 Chemicals & Raw Materials
58 Materials of Construction
59 Compressors

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BUSINESS NEWS

PLANT WATCH

Linde and Samsung Engineering to build ethylene plant in India

January 7, 2009 — The Linde Group (Munich, Germany) and its consortium partner Samsung Engineering Co. have been awarded the contract to build a turnkey ethylene plant in Dahej, India. The plant, commissioned by the Indian company OPAL, a subsidiary of the state-owned ONGC (Oil and Natural Gas Corp. Ltd.), is part of a new petrochemical complex. It will produce 1.1 million ton/yr of ethylene, 400,000 ton/yr of propylene, 150,000 ton/yr of benzene and 115,000 ton/yr of butadiene. This plant will be the largest of its kind in India and one of the largest ethylene plants in the world.

Axens awarded petrochemical complex in Kazakhstan

January 5, 2009 — Kazakhstan's JSC Trade House KazMunaiGaz has selected Axens' (Rueil-Malmaison Cedex, France) ParamaX Technology Suite for the first major aromatics complex to be located at the Atyrau refinery in Kazakhstan. The Atyrau refinery processes up to 5.0 million metric tons (m.t.) per year of crude oil. The grassroots plant will produce 496,000 m.t./yr paraxylene and 133,000 m.t./yr benzene. Plant startup is planned for the 2012–2013 timeframe.

Uhde wins several contracts for aromatics plants

December 18, 2008 — Uhde GmbH (Dortmund, Germany) has been awarded a contract by Risun Chemical Co. of China to build an aromatics plant at Tangshan some 150 km east of Beijing. The new plant will produce benzene, toluene and xylene from coke-oven light oil. High-purity aromatics are processed by the chemical industry into essential intermediate products used, for example, in the production of plastics. The plant, which is designed for a throughput capacity of 200,000 m.t. of coke-oven light oil per year, is due to come on stream in 2010 and joins a major high-purity aromatics plant being built by Xingtai Risun Coal & Chemical Co., a subsidiary of the Risun Group at Xingtai, using Uhde's process. This second plant will start up around mid-2009, and together the two plants will mean that the Risun Group will gain a production capacity of 260,000 m.t./yr of high-purity aromatics.

Dow Corning invests in emerging, global solar-power industry

December 17, 2008 — Dow Corning Corp. (Midland, Mich.) has announced several billion dollars of investment to provide critical materials to the solar technology industry. This investment includes construction of a new monosilane manufacturing facility in Hemlock, Mich. The investment also includes up to $3.0 billion at Dow Corning joint ventures, Hemlock Semiconductor Corp. and Hemlock Semiconductor LLC. The companies will expand Hemlock Semiconductor Corp.'s existing Michigan manufacturing facility and build a new site in Clarksville, Tenn. to increase manufacturing capacity for polycrystalline silicon (polysilicon). Construction of both the polysilicon expansions and the new monosilane site are to begin immediately.

MERGERS AND ACQUISITIONS

Dow and Süd-Chemie seek alternative routes to chemicals

January 22, 2009 — The Dow Chemical Co. (Midland, Mich.) and Süd-Chemie AG (Munich, Germany) have announced an agreement to research alternative routes to produce chemicals that help reduce dependence on traditional sources of oil and gas. The collaborative research aims to convert synthesis gas (syngas) into building-block chemicals in a more efficient and economical process. The two companies will be developing the terms of the joint R&D effort within a couple of months with a plan to initiate the program in April 2009. Focusing on the development and manufacturing of catalysts for the conversion of syngas to chemicals and the direct conversion of syngas to olefins, this joint research program will be conducted at Dow's Terneuzen, Netherlands, site and at Süd-Chemie's catalyst R&D centers in both Germany and the U.S.

AkzoNobel finalizes acquisition of Germany-based LII Europe...

January 19, 2009 — AkzoNobel (Amsterdam, Netherlands) has strengthened its European chemicals portfolio with the acquisition of the business and assets of LII Europe. The acquired activities will be integrated into AkzoNobel Industrial Chemicals. LII Europe operates a multi-client chlorine cluster on the Hoechst Industrial Park near Frankfurt. The company also runs a chlorinated hydrocarbon plant, along with calcium chloride and solid caustic facilities. Financial details were not disclosed.

...and divests non-stick coatings activities

January 16, 2009 — AkzoNobel has agreed to divest its non-stick coatings business to privately owned, U.S.-based Whitford Worldwide. Financial details have not been disclosed. The deal involves AkzoNobel's global cookware and bakeware activities, which operate out of five sites in the U.S., China, India, Brazil and Italy. The transaction is expected to be completed in the 1st Q of 2009.

Samsung Petrochemical and PSE collaborate on PTA optimization

January 14, 2009 — Samsung Petrochemical Co. (Seoul, Korea), a producer of purified terephthalic acid (PTA), and Process Systems Enterprise (PSE), providers of modeling technology and process optimization services, have signed an agreement for joint development of new high-performance technologies for PTA production. The new developments will aim primarily at reducing operating costs and improving product quality.

Total purchases 50% stake in AMSO and will develop shale oil in Colorado

January 14, 2009 — Total (Courbevoie, France) announced that it will acquire a 50% stake in IDT Corp.'s American Shale Oil, LLC (AMSO) subsidiary. Under the terms of the agreement, Total and IDT will jointly develop a research and demonstration program to produce and commercialize shale oil using a new *in-situ* technology in western Colorado.

Borealis launches Mobility Business Unit for automotive applications

January 13, 2009 — Borealis (Vienna, Austria) is launching a new business unit dedicated to future development of its automotive business. The Business Unit Mobility, which came into being on January 1, will be led by Harald Hammer, previously CEO of Borouge Marketing Co., a Borealis joint venture based in Singapore. The new business unit will also incorporate Borealis's battery application business. ■

Dorothy Lozowski

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Economic Indicators

2008 2007

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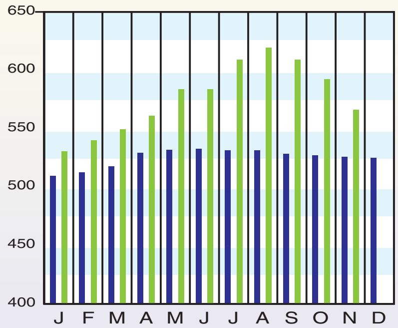
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Nov. '08 Prelim.	Oct. '08 Final	Nov. '07 Final
***CE* INDEX**	566.1	592.2	526.0
Equipment	681.3	720.0	624.4
Heat exchangers & tanks	655.8	711.7	593.5
Process machinery	641.1	664.7	597.9
Pipe, valves & fittings	831.8	864.0	731.1
Process instruments	415.8	439.0	416.9
Pumps & compressors	896.5	893.0	842.9
Electrical equipment	461.7	471.9	437.4
Structural supports & misc	718.0	771.8	660.4
Construction labor	325.5	326.2	317.9
Buildings	513.5	522.8	477.1
Engineering & supervision	350.6	351.3	357.0

Annual Index:
2000 = 394.1
2001 = 394.3
2002 = 395.6
2003 = 402.0
2004 = 444.2
2005 = 468.2
2006 = 499.6
2007 = 525.4

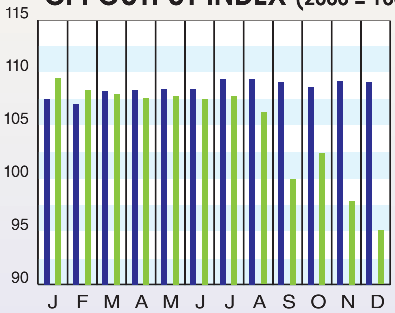


Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics

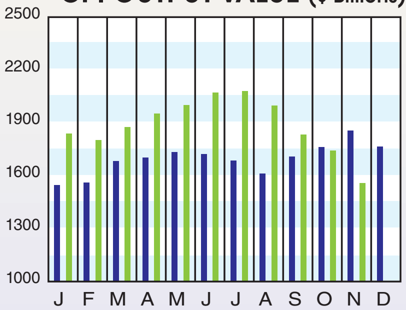
CURRENT BUSINESS INDICATORS

	LATEST		PREVIOUS				YEAR AGO	
CPI output index (2000 = 100)	Dec. '08	= 95.1	Nov. '08	= 97.9	Oct. '08	= 102.4	Dec. '07	= 109.1
CPI value of output, $ billions	Nov. '08	= 1,558.4	Oct. '08	= 1,744.1	Sept. '08	= 1,835.2	Nov. '07	= 1,858.6
CPI operating rate, %	Dec. '08	= 69.9	Nov. '08	= 72.1	Oct. '08	= 75.5	Dec. '07	= 81.5
Construction cost index (1967 = 100)	Jan. '09	= 795.9	Dec. '08	= 796.1	Nov. '08	= 800.9	Jan. '08	= 753.2
Producer prices, industrial chemicals (1982 = 100)	Dec. '08	= 225.2	Nov. '08	= 260.6	Oct. '08	= 286.9	Dec. '07	= 245.1
Industrial Production in Manufacturing (2002=100)*	Dec. '08	= 102.5	Nov. '08	= 105.0	Oct. '08	= 107.4	Dec. '07	= 113.8
Hourly earnings index, chemical & allied products (1992 = 100)	Dec. '08	= 145.0	Nov. '08	= 146.1	Oct. '08	= 143.9	Dec. '07	= 142.8
Productivity index, chemicals & allied products (1992 = 100)	Dec. '08	= 123.3	Nov. '08	= 125.3	Oct. '08	= 129.7	Dec. '07	= 136.2

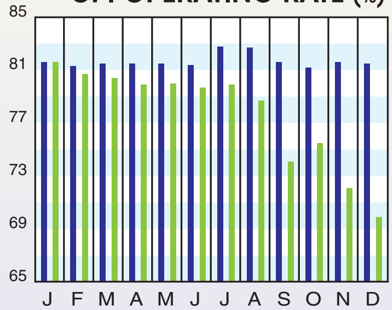
CPI OUTPUT INDEX (2000 = 100)



CPI OUTPUT VALUE ($ Billions)



CPI OPERATING RATE (%)

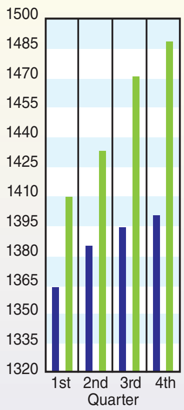


*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.

Current business indicators provided by Global insight, Inc., Lexington, Mass.

MARSHALL & SWIFT EQUIPMENT COST INDEX

(1926 = 100)	4th Q 2008	3rd Q 2008	2nd Q 2008	1st Q 2008	4th Q 2007
M & S INDEX	1,487.2	1,469.5	1,431.7	1,408.6	1,399.2
Process industries, average	1,561.2	1,538.2	1,491.7	1,463.2	1,452.3
Cement	1,553.4	1,522.2	1,473.5	1,448.1	1,435.3
Chemicals	1,533.7	1,511.5	1,464.8	1,438.5	1,427.9
Clay products	1,524.4	1,495.6	1,453.5	1,429.1	1,415.0
Glass	1,448.1	1,432.4	1,385.1	1,359.7	1,348.8
Paint	1,564.2	1,543.9	1,494.8	1,467.6	1,457.1
Paper	1,462.9	1,443.1	1,400.0	1,377.7	1,369.2
Petroleum products	1,668.9	1,644.4	1,594.4	1,555.8	1,543.7
Rubber	1,604.6	1,575.6	1,537.5	1,512.3	1,500.1
Related industries					
Electrical power	1,454.2	1,454.4	1,412.8	1,380.4	1,374.9
Mining, milling	1,567.5	1,546.2	1,498.9	1,473.3	1,460.8
Refrigeration	1,818.1	1,793.1	1,741.4	1,711.9	1,698.8
Steam power	1,521.9	1,499.3	1,453.2	1,426.8	1,416.4



Annual Index:

2001 = 1,093.9	**2003 = 1,123.6**	**2005 = 1,244.5**	**2007 = 1,373.3**
2002 = 1,104.2	**2004 = 1,178.5**	**2006 = 1,302.3**	**2008 = 1,449.3**

CURRENT TRENDS

The CEPCI continues its decline in the November preliminary numbers (top), reflecting a substantial decrease in copper and steel prices caused by an overall economic slowdown worldwide. Meanwhile, the drop in the CPI operating rate (middle) from this time last year is the largest since the worst of the 1973 recession with one exception: the Sept. 2008 number, which reflected unusual shutdowns resulting from two Gulf Coast hurricanes.

Visit www.che.com/pci for more on the CEPCI. ■