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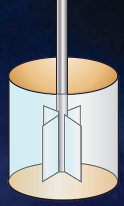

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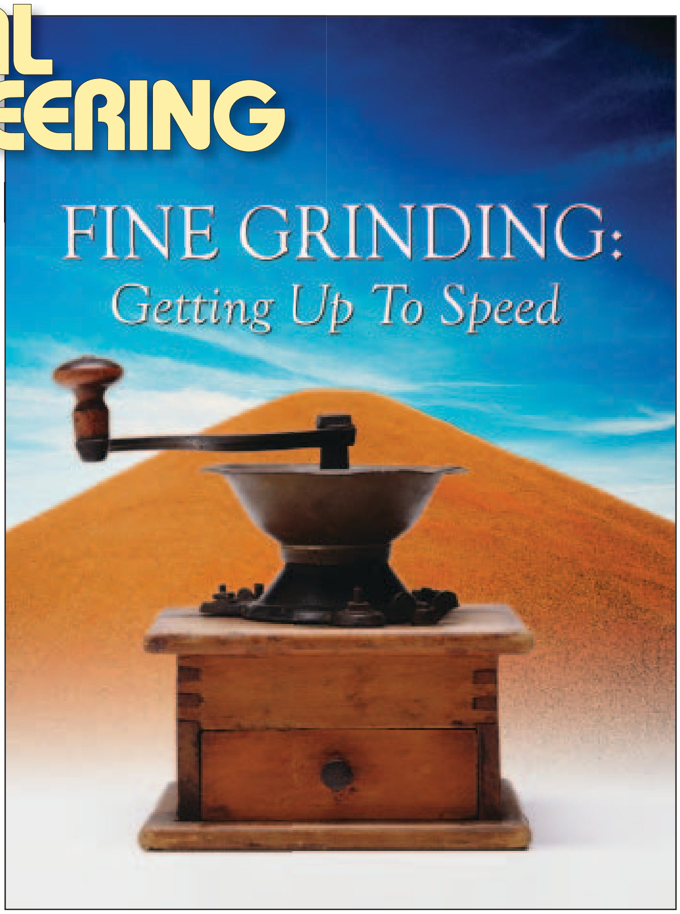

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Editor's Page

A new 'lease' on CPI life?

While the worst of the recession may very well be over for the global economy in general, the downstream effects in the chemical process industries (CPI) will take awhile to flush themselves out. Second quarter financial reports were released last month, with most of the good news loosing luster in the shadow of the same period last year. Meanwhile, credit options remain tight. Based on these factors alone, the job of any chemical engineer who must justify capital expenditures is difficult at best. But, emerging flexibility in how the CPI pays for both equipment and services could change the way we look at equipment improvements, even beyond this particular downturn.

The new approach is a twist on the familiar model of looking at so-called lifecycle costs or total costs of ownership. For years, vendors have used lifecycle cost analysis as a selling point for premium equipment and services, arguing that the initially higher up-front investment will save the customer money over the longterm. But at the bottom of a recession and the last half or quarter of a fiscal year, longterm thinking is often superseded by short-term constraints. Seeing the writing on the wall, a number of equipment and service providers in the software, automation and control field have been working on creative ways around such obstacles. In short, they are transforming capital expenditures into operating ones, thereby avoiding the hurdle of large up-front investments altogether.

One such example is the Lifecycle Management (LCM) program offered by Honeywell Process Solutions (Phoenix, Ariz.; www.honeywell.com/ps). In a multi-year service agreement, Honeywell and the customer establish an automation roadmap that leads to either an "electronic refresh" or a complete migration during the term of the contract, says Jose Simon, business director Lifecycle Services. The key here, though, is that the LCM program offers both flexibility and predictability in how the choices are financed. The costs can be redefined as maintenance expenses, for example. "Instead of paying in one bucket, you pay over time," Simon says, citing five years as an example term.

Such an option is especially attractive for the large number of aging plants around the world, which are looking at high maintenance bills in the coming years, anyhow. If these plants can redirect the funds that would be needed for repair into procuring newer models that are also cheaper to operate, the approval process becomes a lot easier. A CPI plant can start down the path to modernization today and get there incrementally with less financial risk.

And in the wake of second quarter earnings that were announced last month, options with less financial risk look better and better. Even companies that have seasoned the storm reasonably well have a lot of economic ground to recover. The Saudi Basic Industries Corp. (SABIC; Riyadh, Saudi Arabia; www.sabic.com), for instance, reported a 76% drop in income from that of the same quarter in 2008 due to the sharp decline in demand and the prices of petrochemicals, plastics and metals. Meanwhile, DuPont (Wilmington, Del.; www.dupont.com) reported a 61% drop, PPG Industries (Pittsburgh, Pa.; www.ppg.com) experienced a 42% drop, and the list goes on.

To these and other CPI firms that must protect their budget over the remainder of their 2009 fiscal year, the prospect of shoring up longterm improvements without taking an immediate budget hit probably sounds like an unrealistic expectation. In any case, the potential is quite intriguing. Imagine if the economic recovery of today's CPI were paired with safer, more reliable and more efficient operations for tomorrow. ■

Rebekkah Marshall

Letters

Optimal cooling systems

The following comments relate to the May article, Optimal Cooling Systems for Coastal Plants (pp. 45–48).

1. The psychrometric chart (Figure 4, p. 47) lacks the wet bulb temperatures. These are essential for using the chart and are represented by the inclined lines.

2. Equation (1) on p. 46 is incorrect. Firstly, $P^{\hat{}}_{water}$ is the partial pressure of water *vapor* in air at ambient temperature, and P^{sat}_{water} is the saturation pressure of water *vapor* in air at ambient temperature. Secondly, the equation that defines the relative humidity should be multiplied by 100, because the relative humidity of air is expressed in percentage.

Giovanni S. Crisi
Sao Paulo, Brazil

Author's reply

1. The psychrometric chart mentioned in the article is just a descriptive chart that has been included in the article not as a reference for design but for explanation of different scenarios included in the article. So the inclusion of all the properties of air in the chart is not necessary for the mentioned purpose. Complete and accurate psychrometric data can be found in many chemical and mechanical engineering handbooks.

2. Firstly: Partial pressure is only used for the *gas phase* (and not liquid or solid phases), so partial pressure of water means pressure of water vapor and there is no difference between the two descriptions. Secondly: The definition of relative humidity in all references is the ratio of partial pressure of water vapor to saturated vapor pressure of water at the ambient temperature (dry bulb temperature). But expression of it is normally performed as percentage due to fluency.

Postscripts, corrections

July, The Shotgun Approach, pp. 44–48: Equation (2) contains an error. The correct equation should have S_d, not S_b, and appears below:

$$t = \frac{P_{\max} \cdot D_{bo}}{\left(2 \cdot S_d + P_{\max}\right)} \tag{2}$$

Meanwhile, the author would like to point out that there is a potential risk that the operating conditions using steel shot, as summarized in Table 3, could result in boiler tube damage. To minimize this risk, the steel shot used in the shotgun ammunition should be annealed by appropriate heat treatment before use. In doing so the shot, instead of the tubes, will preferentially deform on impact.

Additionally, the "Arrangement of Equipment" sketch on p. 47 is meant to be used only when the interior of the boiler operates below atmospheric pressure. The arrangement must be appropriately modified when the interior of the boiler operates above atmospheric pressure. In either case external insulation must be provided on that portion of the barrel extending inside the boiler wall.

A revised version of the article may be obtained by searching for the article title at www.che.com ■

Calendar

NORTH AMERICA

ISA's 4th Annual Marketing and Sales Summit: Managing Through the Turbulence and Tumult. International Society of Automation (ISA; Research Triangle Park, N.C.). Phone: 919-549-8411; Web: isa.org/mktsales
Boston, Mass. **September 9–11**

24th Annual WateReuse Symposium. WateReuse Assn. (Alexandria, Va.), and co-sponsored by the American Water Works Assn. (Denver, Colo.) and the Water Environment Federation (Alexandria, Va.). Phone: 703-548-0880; Web: watereuse.org
Seattle, Wash. **September 13–16**

38th Turbomachinery Symposium. The Turbomachinery Laboratory at Texas A&M University (College Station, Tex.), co-located with the ASME Gas Turbine Users Symposium 2009; Phone: 979-862-1012; Web: turbolab.tamu.edu/articles/turbo_symposium
Houston, Tex. **September 14–17**

ASM Heat Treating Society Conference Exposition. ASM International (Novelty, Ohio.). Phone: 805-677-4288; Fax; 805-654-1676; Web: asminternational.org
Indianapolis, Ind. **September 14–17**

9th Annual SPE Automotive Composites Conference & Exhibition. Society of Plastics Engineers International (SPE) Automotive Division (Troy, Mich.). Phone: 248-244-8993; Web: speautomotive.com/comp.htm
Troy (Detroit), Mich. **September 15–17**

OSHA Dust Explosion Inspection Preparatory Training Course. Chilworth Technology (Plainsboro, N.J.). Phone: 609-799-4449; Web: chilworth.com/OSHAtrainingcourse.pdf
Columbus, Ohio **September 24**

ACEEE 5th National Conference on Energy Efficiency as a Resource. American Council for an Energy-Efficient Economy (Washington, D.C.). Phone: 302-292-3966; Web: aceee.org/conf/09ee/09eeindex.htm
Chicago **September 27–29**

2009 Gasification Technologies Conference. Gasification Technologies Council (Arlington, Va.). Phone: 703-276-0110; Web: gasification.org
Colorado Springs, Colo. **October 4–7**

International Acid Gas Injection Symposium. Sphere Technology Connection Ltd. (Calgary, Alta.). Phone: 403-619-6215; Web: spheretechconnect.com
Calgary, Alta. **October 5–6**

WaterSmart Innovations Conference and Exposition. American Waterworks Assn. (AWWA; Denver, Colo.), Southern Nevada Water Authority, and U.S. Environmental Protection Agency. Fax: 702-731-3580; Web:

watersmartinnovations.com
Las Vegas, Nev. **October 7–9**

5th Annual Comsol Conference 2009. Comsol (Burlington, Mass.). Phone: 781-273-3322; Web: comsol.com/conference2009/usa/
Boston, Mass. **October 8–10**

WEFTEC 09. Water Environment Federation (WEF; Arlington,Va.). Phone: 708-344-9070; Web: weftec.org
Orlando, Fla. **October 10–14**

BioProcess International Conference & Exhibition. IBC Life Sciences (Westborough, Mass.). Phone: 800-390-4078; Web: ibclifesciences.com/bpi/us
Raleigh, N.C. **October 12–16**

Centrifugal Compressor Operations for 21st Century Users — Short Course. The Turbomachinery Laboratory at Texas A&M University (College Station). Phone: 979-845-7417; Web: turbolab.tamu.edu/articles/centrifugal_compressor_operations_for_21st_century
Houston **October 27–29**

EUROPE

RadTech Europe 2009. RadTech Europe Association (Hague, Netherlands). Phone: + 31 70 3123920; Web: european-coatings/radtechcom
Nice, France **September 13–15**

14th International Congress for Battery Recycling. ICM AG (Birrwil, Switzerland). Phone: + 41 (0) 62 785 1000; Fax: + 41 (0) 62 785 1005; Web: icm.ch
Geneva, Switzerland **September 16–18**

24th European Photovoltaic Solar Energy Conference and Exhibition 2009. WIP Renewable Energies (Munich, Germany). Phone: +49 (0) 6181 9828042; Web: www.photovoltaic-conference.com
Hamburg, Germany **September 21–25**

Entsorga-Enteco 2009: The International Trade Fair for Waste Management & Environmental Technology. Koelnmesse (Chicago, Ill.). Phone: 773-326-9925; Web: entsorga-enteco.com
Cologne, Germany **October 27–30**

ASIA & ELSEWHERE

18th international Conference on Plastic Optical Fibers 2009. Magic Touch Consultancies (International) Pty Ltd (Sydney, Australia). Phone: +61 2 9524 1799; Web: pof2009@mtci.com.au
Syndney, Australia **September 9–11**

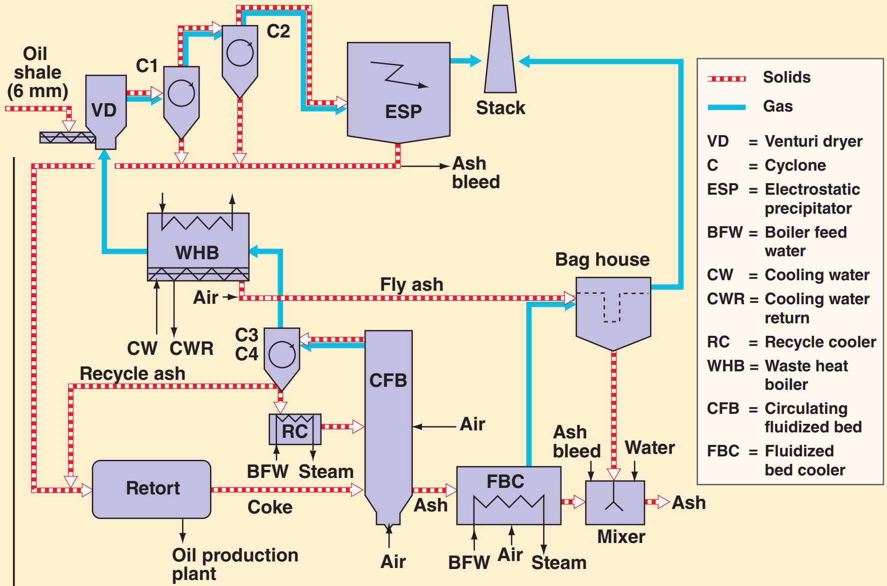
4th World Recycling Forum Shanghai '09. ICM AG (Birrwhil, Switzerland). Phone: + 41 62 785 1000; Web: ich.ch
Shanghai, China **November 10–13** ■

Suzanne Shelley

Chementator

Edited by Gerald Ondrey August 2009

Capacity to double for an oil-shale process



Outotec GmbH (Oberursel, Germany), a 100% daughter company of Outotec Oy (Helsinki, Finland; www.outotec.com) has received a €109-million contract for the design, delivery, construction and commissioning of a new oil-shale processing plant to be built in Narva, Estonia for Eesti Energia (Tallin, Estonia; www.energia.ee). Scheduled for commissioning in early 2012, the facility will process over 2.2-million metric tons (m.t.) of oil shale per year, producing approximately 290,000 m.t./yr of crude oil. The plant will be the first commercial application of the Enefit-280 process, a modified Galoter process developed by the two companies.

The solid heat carrier process (Galoter process) was first introduced in 1953, and scaled up to 140 m.t./h (Enefit 140 process) in the 1980s. Currently, two Enefit-140 units, operated by Eesti Energia Oil & Gas in Narva, are converting about 1.5-million m.t./yr of oil shale into about 160,000 m.t./yr of oil. In the Enefit 140 process, oil shale is first ground to a size of less than 20 mm, dried in a lift-pipe, then mixed with hot (800°C) ash produced by combustion of spent oil shale in a separate furnace. The mixture is then pyrolyzed in a retort at 520°C. The pyrolysis gas is then separated from the spent shale in a cyclone, and the ash and semi-coke transported to the separate furnace to make hot ash for pyrolysis.

Enefit, which combines the Galoter process with Outotec's circulating fluidized-bed technology (flowsheet), has the advantages — besides doubling the unit capacity — of high thermal efficiency and the complete combustion of the spent shale after the oil has been extracted, says Peter Weber, president metals processing, Outotec GmbH. Most of the heat is recovered to produce steam for electric power generation. The ash from the process is free of organic carbon and can be landfilled, and the offgas from the process meets European regulations, he adds. Although production costs are not disclosed, Weber says the process is economical for an oil price of $65/bbl (Brent). The two firms established a joint venture to commercialize and market Enefit, targeting the large oil-shale deposits found in the U.S., Brazil, China, Jordan, Russia and Estonia.

A silver-based antimicrobial

Pure Bioscience (El Cajon, Calif.; www.purebio.com) has developed silver dihydrogen citrate (SDC), the first antimicrobial approved by the U.S. Environmental Protection Agency (EPA; Washington, D.C.) in 30 years, with applications in the pharmaceutical, personal care, household, food and textile markets. Pure produces both a pre-formulated, ready-to-use product, and an SDC concentrate for addition to other products. It is highly effective as a hard-surface cleaner, killing the Norovirus, MRSA, VRE, *E. coli*, some influenza viruses, as well as other dangerous bacteria and viruses. It kills bacteria within 30 s and has a residual killing capability of up to 24 h after application, unlike other antimicrobials that disappear upon evaporation.

The technology consists of stabilized ionic silver in a solution of organic acid that is the product of an electrolytic process. The stable bond of the silver ion in SDC allows the Ag^+ to remain in solution while still making it bio-available. Microorganisms view the acid solution as a food source, allowing the pico-scale SDC molecule to enter as well. The Ag^+ then denatures the microbe's DNA, stopping its ability to replicate and killing it.

Aqueous SDC is colorless, odorless, tasteless and non-caustic, and it formulates well with other compounds. It is highly toxic to bacteria, fungi and viruses, but it is non-toxic to humans and animals, having the lowest EPA toxicity category rating of IV. This safe technology was approved by the EPA in June as an active ingredient in the sanitation of food-contact surfaces.

Bioplastic

DSM Engineering Plastics (Sittard, Netherlands; www.dsm.com) has introduced EcoPaXX, a biobased, high-performance engineering plastic that is said to have a zero carbon footprint (100% carbon neutral from cradle to grave). Approximately 70% of EcoPaXX is made from building blocks derived from Castor oil. Based on the long-chain polyamide (PA), PA 410, the new plastic features low moisture absorption and high (250°C) melting point — the highest of all bioplastics — and a high crystallization rate. Such properties make the material suitable for automotive and electrical applications.

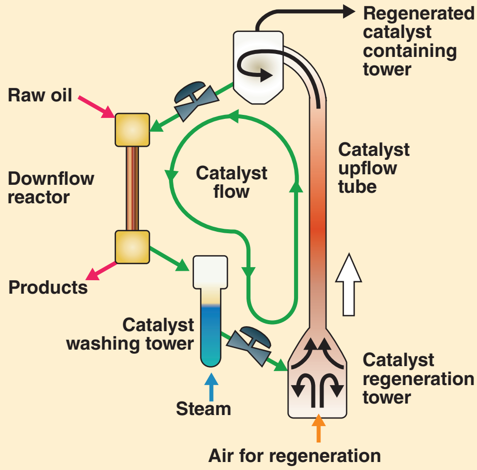
Weed-based biodiesel

Biofuels Manufacturers of Illinois (BMI; Peoria, Ill.; www.bmibiodiesel.com) will develop, construct and operate a 45-MM gal/yr (expandable to 60-MM gal/yr) biodiesel plant, beginning construction as early as this month. In addition to using traditional crops, BMI is working on the development of pennycress as biodiesel feedstock. As a weed, pennycress is unconnected to the issue of growing food for fuel. It grows in the winter, allowing

(*Continues on p. 13*)

Note: For more information, circle the 3-digit number on p. 54, or use the website designation.

Scaleup for a 'downer' FCC process



In October, Nippon Oil Corp. (Tokyo, Japan; www.eneos.co.jp) will start constructing a high-severity fluidized-catalytic cracking (HS-FCC) unit, the first in the world that can produce large amounts of propylene from heavy fuel oils. The unit, located at Mizushima Refinery (Kurashiki-City), will start up in early 2011. The 3,000 bbl/d facility is 100 times larger than the 30 bbl/d HS-FCC demonstration unit that was developed in collaboration with Japan Cooperation Center, Petroleum (JCCP), Petroleum Energy Center (PEC), and Saudi Aramco (*CE*, December 2001, p. 21), and the company says it will scale up by another factor of 10 in a few years.

Hiroji Adachi, executive officer and general manager of the Technical Service Department, commented expectings to start royalty business through licensing this technology. In 2009, the Ministry of Economy, Trade and Industry (METI) will supply two thirds of the approximately $46 million for the project.

In the HS-FCC process, heavy oil is injected into a downflow reactor with powdered catalyst, where the oil is decomposed within 0.5 s at 600°C. (A conventional FCC typically operates at about 500°C, with a contact time of 1–4 s.) The propylene yield is best among all propylene production processes, and high-octane gasoline yield is low compared to FCC but rather high compared to other processes. The process can produce 34% gasoline and 20% propylene, compared to about 50% gasoline and 5% propylene achieved in conventional FCC risers.

Diamond lubricant cuts friction and increases equipment life

The lifetime of steel bearings can be extended by up to eight times by a new synthetic diamond "lubricant," according to its developer, NanoLube, Inc. (Lombard, Ill.; www.diamondlube.com). The lubricant consists of 0.1–4-nm diamond spheres that are dispersed in a light carrier oil (about 5 wt.%) and coated onto the bearings and other friction-prone surfaces of a machine. When the machine is activated, the spheres become embedded in the surface of the metal, forming a smooth, protective barrier that prevents metal-to-metal contact and spalling, and reduces friction. The only contact is between the smooth diamond coatings, says Christopher Arnold, president of NanoLube.

The key to the technology is the company's low-energy plasma process, which produces the tiny spheres from vaporized carbon in an electrical field. This provides advantages over other synthetic diamond processes, says Arnold. For example, conventional synthetic diamonds, produced from graphite at high temperature and pressure, are crystalline with abrasive edges, not spherical.

In side-by-side tests of bearings run by identical motors, bearings treated by the NanoLube product ran cool at 15,700 rpm, while bearings using a conventional lubricant overheated, as did the motor, at 6,400 rpm. Arnold says the treatment cost depends on the application. He estimates, for example, that it would cost about $150 to treat a $20,000 compressor, but the reduction in friction would increase the life of the moving parts eight-fold. He adds that the coating can operate in temperatures from –100 to 2,000°F.

Making fine particles of inhalable drugs

A team from the School of Chemical Sciences and Engineering, at the University of New South Wales (Sydney, Australia; www.unsw.edu.au), has developed a process for the micronization of insulin called Arise (Atomized Rapid Injection for Solvent Extraction). According to BioParticle Technologies Pty. Ltd. (BPT; Sydney; www. bioparticletechnologies.com), the company marketing Arise, the technology offers several advantages over other existing supercritical fluid technologies. The team leader, professor Neil Foster who invented the Arise process, says "this technology allows us to shrink the particle size of existing drugs and make them better suited for pulmonary delivery."

Arise is a supercritical fluid (SCF) precipitation process employing the energized rapid release of organic solutions and the anti-solvent capability of supercritical CO_2 for the precipitation of pharmaceutical compounds from organic solvents. It exploits a pressure differential and rapid injection to atomize organic solutions into a vessel containing supercritical CO_2 without using capillary nozzles. This results in a more homogeneous distribution of organic solution for precipitation to occur within the entire vessel containing the supercritical CO_2. The absence of capillary nozzles also avoids the problems associated with them, such as the tendency to block and clog during processing of viscous or concentrated solutions, says Foster.

In the Arise process, a vessel containing organic solution with dissolved pharmaceutical compounds is pressurized with nitrogen and sealed. By rapidly depressurizing the vessel through a tube (about 1-mm inner dia.), the solution is atomized into another vessel containing supercritical CO_2 under near-isothermal conditions. The extraction of organic solution and the precipitation of previously dissolved pharmaceutical compound occur at this stage.

The process was successfully implemented to generate dry powders of bovine insulin with properties that were highly tunable as a function of anti-solvent pressure. With a pre-injection pressure of 120 bar CO_2 at 40°C, Arise processing of bovine insulin yielded a product with geometrical particle-size distribution almost completely within the prescribed inhalation range of less than 5 µm.

Cellulose-to-aromatics process simplifies BTX production

A single-step method to convert cellulosic biomass into aromatic compounds offers a simpler and more environmentally friendly route to the petrochemical feedstocks benzene, toluene and xylenes (BTX), according to a Massachusetts bioenergy startup company seeking to scale up the technique.

Based on a catalytic fast pyrolysis process developed by University of Massachusetts (Amherst, Mass.; www.umass.edu) researcher George Huber, the technique will generate BTX at costs lower than petroleum-derived BTX, says Anellotech (www.anellotech.com), the startup company formed by Huber to commercialize the process.

"It's a more economical process" than petroleum-based aromatics preparation, explains Anellotech CEO David Sudolsky, in part because the products need no further processing. Process benefits also derive from the fact that no hydrogen or water is required, which eliminates a major waste stream present in biofuel processes like ethanol production. In addition, cellulosic starting material requires no pre-treatment, Sudolsky adds.

The one-step catalytic fast-pyrolysis process involves rapidly heating wood trimmings or other biomass to 600°C in a fluidized bed reactor to form oxygenated compounds. Proprietary zeolite catalysts convert the compounds into industrial chemical-grade BTX.

Anellotech is currently raising capital for a pilot project to demonstrate the technology beyond bench-scale. The pilot plant will process 1–3 ton/d of biomass. The company expects to have a small-scale production facility online in 2014.

Biobased succinic acid pilot effort underway

Pilot-scale production of biobased succinic acid from dextrose has been demonstrated by Myriant Technologies (Quincy, Mass., www.myriant.com). The firm expects commercial production by mid-2010.

The succinic-acid process follows Myriant's successful commercialization with partner Purac (Blair, Neb.; www.purac.com) of a biobased D(–) lactic acid, which began commercial production in June 2008. Succinic acid process relies on an engineered *E. coli* strain with deleted genes, and on off-the-shelf technologies for isolating products.

Myriant says its succinic acid production will be cost competitive relative to petroleum-derived alternatives such as maleic anhydride for polymer, solvent, food, pigment and pharmaceutical applications. "We are not counting on any green premium to be competitive," says Sam McConnell, Myriant senior vice president for Corporate Development.

Biobased succinic acid is thought to avoid some of the price volatility associated with petroleum-derived alternatives. The Myriant process offers significant environmental benefits, including lower greenhouse-gas emissions, McConnell explains, because the process consumes carbon dioxide.

Myriant Technologies is working to produce ton-sized samples that will be evaluated by customers for purity and other product specifications.

(*Continued from p. 11*)

farmers to double crop yields. Pennycress contains 36% oil, twice that of soybeans, while an acre of pennycress can produce 115 gal of biodiesel — more than twice that of soybeans. Growmark (Bloomington, Ill.), a farmer-owned cooperative operating in the midwest U.S. and Canada, will purchase and market the biodiesel produced by BMI.

Mimicing moth eyes

Researchers at the Savannah River National Laboratory (SRNL; Aiken, S.C.; www.srnl.gov) are examining how special coatings that imitate structures found in nature can improve the performance of solar cells, which typically lose about one third of the energy due to reflection. Engineered nanostructured coatings that mimic the way moths' eyes absorb light have been shown to reduce undesirable reflection from 30% to less than 2% on a typical solar cell, says SRNL. Durability testing of the coatings is underway to determine the feasibility of use in harsh environments, including heat, humidity and radiation.

Electro-active polymers

Solvay Solexis SA (Bollate, Italy; www.solvaysolexis.com) has launched solvene, a range of electro-active polymers for applications in printed electronics. The polymer exhibits a number of electro-active behaviors, including: piezo elec-

(*Continues on p. 14*)

Green honors

In June, the U.S. Environmental Protection Agancy (EPA; Washington, D.C.; www.epa.gov) announced the winners of the 2009 Presidential Green Chemistry Challenge Awards. Winners of the Challenge, which promotes R&D of less hazardous alternatives to existing technologies that reduce or eliminate waste in industrial production, are selected by an independent panel convened by the American Chemical Soc. This year's honorees include the following (source, EPA):

- Academic Award: Professor Krzysztof Matyjaszewski, Carnegie Mellon University (Pittsburgh, Pa.; www.cmu.edu), for an alternative process, called Atomic Transfer Radical Polymerization, for manufacturing polymers. The process uses sustainable reducing agents, such as ascorbic acid, and requires less catalyst than alternatives
- Small Business Award: Virent Energy Systems, Inc. (Madison, Wisc.; www.virent.com), for its water-based Bio-Forming process that catalytically converts sugar, starch or cellulose into gasoline, biodiesel or jet fuel
- Greener Synthetic Pathways: Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com), for a solvent-free, biocatalytic process for making esters (cosmetic and personal-care ingredients). The process avoids both strong acids and organic solvents, and requires less energy
- Greener Reaction Conditions: CEM Corp. (Matthews, N.C.; www.cem.com), for a fast, automated process to analyze for proteins in food samples. The system can eliminate 5.5-million pounds of hazardous waste generated by traditional tesing in the U.S. each year
- Designing Greener Chemicals: Proctor & Gamble Co. (Cincinnati, Ohio; www.pg.com) and Cook Composites and Polymers Co, (North Kansas City, Mo.; www.ccponline.com), for Chempol MPS paint formulations, which use biobased Sefose oils — made from sugar and vegetable oil — to replace petroleum-based solvents

Making SunCatchers instead of cars

Stirling Energy Systems (SES; Phoenix, Ariz.; www.stirlingenergy.com) and Tessera Solar (Houston; www.tesserasolar.com) recently unveiled four, newly designed solar-power collection dishes at Sandia National Laboratories' National Solar Thermal Test Facility (Albuquerque, N.M.). The refined design of SunCatchers will be used in commercial-scale deployment of the units in 2010 (see also Solar's Second Coming, *CE*, March, pp. 18–21).

SunCatchers use mirrors attached to a parabolic dish to focus sunlight onto a receiver, which transmits the heat to a Stirling Engine — a sealed system filled with hydrogen. As the H_2 heats or cools, its pressure rises and falls, driving a piston inside the engine; this mechanical energy is used to drive a generator for making electricity.

Compared to its predecessor, the new SunCatcher: is about 5,000 lb lighter; is round instead of rectangular, which allows more efficient use of steel; has improved optics; consists of 60% fewer engine parts; and has fewer mirrors (40 instead of 80). The mirrors are formed into parabolic shape using stamped sheet metal, similar to the hood of a car. "By utilizing the automotive supply chain to manufacture the SunCatcher, we're leveraging the talents of an industry that has refined high-volume production through an assembly line process," says SES CEO Steve Cowman. More than 90% of the components will be manufactured in North America.

SES is planning the construction of a commercial-scale reference plant later this year, and has a goal of producing 1,000 MW by the end of 2012.

An alternative to chlor-alkali

Earlier this year, NSR Technologies (Decatur, Ill.; www.nsr-tech.com) commercialized its patented process for producing potassium hydroxide (45–50 wt.%) and dilute hydrochloric acid via a membrane separations technology. The company's flagship production facility in Decatur, Ill. is the first commercial application of this process says Dr. Kris Mani, NSR's president and CEO.

Current producers of commercial strength KOH manufacture it via the chlor-alkali route. NSR uses a membrane electrodialysis (ED) process to convert salt to value-added chemicals. Sodium chloride and potassium chloride are converted to the corresponding acid and alkalis: HCl; and sodium hydroxide and KOH (caustic potash). The process, which occurs in an aqueous medium, uses ion exchange membranes and an electrical driving force to effect the separation and rearrangement of the raw material into the acid and alkali products. The requisite membranes are assembled in NSR's proprietary IonSel cell stacks.

Additional processing steps, such as ion exchange, chromatography and evaporative concentration, are used as required to obtain products of commercial strength and purity.

NSR's production process is more energy efficient than the chlor-alkali route, consuming 40% fewer kilowatt-hours per ton of caustic produced, says Mani. It does not involve the production or combustion of chlorine gas, and allows production to occur from more compact plants located near end users. NSR's products are also free of oxidizing species (hypochlorite and chlorate).

A replacement for Cr^{+6}

Aculon, Inc. (San Diego, Calif.; www.aculon.com) has developed a formulation of its proprietary SAMP technology (Self-Assembled Monolayer of Phosphate) that can be used as an alternative to hexavalent chromium used in primers and conversion coatings to increase the adhesion of coatings to surfaces. The new SAMP formulation can immediately benefit industries using Cr^{+6} as a spray-driven primer, with applications such as golf club heads, electric circuit boards and beverage cans — anywhere that paint needs to adhere to and be durable on stainless steel, Ti and Al, says the firm.

SAMP technology can coat surfaces to impart hydrophobicity, adhesion or corrosion inhibition. Such properties are achieved through covalent bonding between the SAMP and the material to which it is applied. The phosphonate is a phosphorous acid that combines a reactive phosphonic acid "head" and a carbon-based "tail" connected by a stable C–P bond. The heads react with the surface through metal-phosphorous bonds, and the tails stick out from the surface to provide the desired chemical functionality. ■

(*Continued from p. 13*)

tricity, converting a mechanical stress into electricity or reversibly deforming in an electric field; pyro electricity, converting thermal energy into electrical energy; and ferro electricity, the ability to switch its polarization. The polymer also has an intrinsic high K constant, which is advantageous for use in transistors and capacitors, says the firm.

HT heat-transfer fluid

Solvay Solexis (see story above) has also launched a new family of heat-transfer fluids — the Galden Ultra High Boilers. The new fluid is said to feature the highest boiling points among fluorinated fluids and a very low evaporation tendency. Application targets (in the temperature range from 150 to 270°C) include photovoltaic-cell manufacturing, the solar-thermal industry, heating fluids, and the metallurgical and energy sectors.

Printable batteries

Printable batteries that can be produced cost effectively on a large scale have been developed by researchers at the Fraunhofer Institute for Electronic Nano Systems (ENAS; www.enas.fraunhofer.de), the Technical University of Chemnitz, and Menippos GmbH (all Chemnitz, Germany; www.menippos.de). The battery is composed of different layers — a zinc anode and a manganese cathode, among others — and produced by a silk-screen printing process. The non-rechargeable batteries deliver 1.5 V, are less than 1-mm thick and weigh less than 1 g. Prototypes have been made in the laboratory, and first commercial products could be ready by year's end.

Cleaner coal

Last month, Foster Wheeler AG (FW; Zug, Switzerland; www.fwc.com) commissioned the world's largest circulating fluidized-bed steam generator, which is also the world's first to incorporate the Benson vertical-tube supercritical steam technology. Owned by Polish utility company Południowy Koncern Energetyczny SA, the CFB at Lagisza power plant produces 460 MWe of electric power at an efficiency that is "well above" that of typical coal plants, says FW. ❑

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Technology Showcase

MONITORING AIR EMISSIONS

New requirements are spurring strong demand in air pollution monitoring

Robert McIlvaine, McIlvaine Co.

Substantial technological advances to meet the growing regulatory scrutiny of a wide variety of pollutants have taken place over the past 50 years. In the last few years, the increased complexity in regulations in developed countries has been even more accelerated, challenging the chemical process industries (CPI) and their suppliers of air-monitoring equipment to reach new heights. In addition, developing countries are implementing their programs for continuous air monitoring. Another substantial trend is the monitoring of air pollutants as part of the optimization of the manufacturing process. This trio of developments will result in double-digit growth in the need for air pollution monitoring in the next several years. Some of the specifics of these trends are outlined here.

Fine particles

It has been determined that fine particles are more damaging to human health than larger ones. New regulations in the U.S. require states to reduce the quantity of fine particles in ambient air. The rule addresses particles smaller in diameter than 2.5 microns ($PM_{2.5}$). The measurement for the regulation is made very difficult by the inclusion of condensable (vapors that condense to droplets at ambient temperature) as well as discrete particles. Periodic measurement methods are still under review. The fact that continuous measurement methods are not clearly established creates both an opportunity and a problem for those trying to make the measurements, as well as for the industry that supplies the measuring instruments.

One approach is to measure discrete particles and sulfur trioxide and then aggregate the two measurements. Another involves condensing the gas prior to measurement. The one certainty is that the costs of both periodic and continuous measurements will increase.

Mercury

Mercury now needs to be continuously measured at U.S. power plants, which have already spent $400 million in new continuous-emissions-monitoring systems (CEMS). However, the vacature of the Clean Air Mercury Rule has eliminated the immediate requirement for continuous measurement, except for local regulations that have their own rules. A new federal rule will be promulgated in the next year or two in the U.S. It is anticipated that each plant will have to reduce mercury to a level below a stipulated weight per unit of flue gas. This will require continuous mercury monitors on all power plant stacks. Cement kilns and gold-mining operations will also need to install monitors.

Two approaches to measurement are considered acceptable. One is an instrument method. The other is with sorbent traps. These traps capture the mercury for a period of up to two weeks and then are replaced by fresh traps. The removed trap is then analyzed in a laboratory to determine the weight of mercury captured during the period.

The advantage of the trap method is lower cost. The disadvantage is that the trap cannot be used for process control, whereas instrument-based CEMS are used to control the amount of activated carbon injected into the gas stream in order to maintain the required removal efficiency.

As mentioned, cement kilns in the U.S. will also need to be equipped with mercury monitors under proposed rules. In most developed countries, mercury needs to be measured at waste incineration plants. In Europe, waste incinerators and coal-fired plants co-firing sewage sludge are required to limit mercury and to install mercury monitors. China has a mercury program that is presently in the research stage.

Air toxins

The U.S. now considers power plants to be emitters of hazardous air pollutants, which will result in requirements to utilize maximum-achievable-control technology. The concern is the large number of toxic pollutants emitted from coal-fired plants.

Table 1 shows the environmental burden from existing coal-fired plants. The combination of nickel, selenium, barium, zinc, vanadium, hydrochloric acid, sulfuric acid mist, hydrogen fluoride and ammonia is much higher in weight and equal in toxicity to the mercury. In addition there are other metal toxins, such as arsenic, beryllium, lead, and cadmium, that are present in coal-

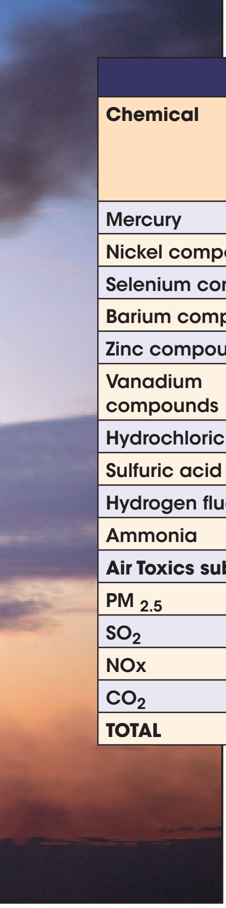

TABLE 1. U.S. AIR SOURCE ENVIRONMENTAL BURDEN

Chemical	Environmental Burden Index	U.S. Coal Emissions (1,000 tons)	Other Industrial Sources (1,000 tons)	Coal Environmental Burden (1,000 tons)	Environmental Burden Other Sources	New Fleet of Coal Plants
Mercury	10,000,000	0.05		500,000		
Nickel compounds	100,000	0.35		35,000		
Selenium compounds	100,000	0.215		21,500		
Barium compounds	10,000	0.215		21,500		
Zinc compounds	10,000	0.67		6,700		
Vanadium compounds	10,000	0.615		6,150		
Hydrochloric acid	1,000	267		267,000		
Sulfuric acid	1,000	58		58,000		
Hydrogen fluoride	1,000	28		28,000		
Ammonia	1,000	2.3		2,300		
Air Toxics subtotal			35	946,150	500,000	100,000
$PM_{2.5}$	1,000	500	250	500,000	250,000	50,000
SO_2	100	9,000	3,200	900,000	320,000	90,000
NOx	100	4,000	3,900	400,000	390,000	40,000
CO_2	1	1,700,000	300,000	1,700,000	300,000	1,200,000
TOTAL				**4,446,150**	**1,760,000**	**1,480,000**

plant flue gases but at relatively low quantities.

A number of new coal-fired plants are being constructed under permits that require them to meet very low levels of specific pollutants, such as cadmium and beryllium. The cost of continuously monitoring each pollutant would be prohibitive. The U.S. Environmental Protection Agency (EPA; Washington, D.C.) is therefore considering using total particulate matter as a surrogate.

Another approach is to use a multi-metal analyzer and calculate the weighted toxicity or burden. In Table 1, CO_2 is rated with a burden unit of 1. Vanadium is 10,000 times more toxic and nickel is 100,000 times more toxic. Multi-metal analyzers are available at reasonable cost.

If total particulate matter is used as a surrogate, the limits would likely be lowered to reflect the need for toxin reduction. It is agreed that the present system of measuring opacity instead of mass is too inaccurate to serve as the basis for measuring the low particulate-matter levels associated with toxin reduction, therefore, mass monitoring will likely be required.

Mass monitoring is already required in Europe. In the U.S. it has been applied to incinerators and to some power plants, which agreed to install the devices as parts of settlements for air violations. This requirement for mass monitors could generate costs of over $250 million in the U.S. during the initial installation phase.

Carbon dioxide

The EPA has classified CO_2 as an air pollutant. This means that ambient, periodic stack and continuous stack monitoring will rise substantially. Existing CEMS will, by and large, be used for measurement, so the cost for new hardware will not be very significant, but those for services including analysis and stack testing will increase.

The biggest increase will be the need for ambient measurements. The models predicting various calamities need to be supported by actual periodic or continuous measurement at key locations in the water, ice, air, and so on. In the air, there are big swings in CO_2 levels from season-to-season and locality-to-locality.

Instruments have been developed that can distinguish between CO_2 that is anthropogenic (derived from human activity) and that which is naturally generated. Since 97% of the CO_2 is currently generated by natural sources, it will be important to identify the anthropogenic segment.

Trends and financial impact

The future of air pollution monitoring is tied closely to energy sources. If coal use were to be reduced, the market for CEMS would be significantly impacted, negatively. However, the use of coal is likely to increase, not decrease. World coal-fired-power-plant capacity will grow from 1,759,000 MW in 2010 to 2,384,000 MW in 2020. Some 80,000 MW will be replaced, so there will be 705,000 MW of new coal-fired boilers built. The annual new coal-fired boiler sales will average 70,000 MW.

A historic change is taking place in the Middle East where huge investments in petrochemical plants are being made. This will result in very substantial markets both for air pollution CEMS and for process analyzers for sulfur and other acid gases.

Waste-to-energy is the second largest market after power. This market will continue to grow throughout the world. The U.S. is well behind Europe and Asia in construction of waste-to-energy plants. However, this situation is changing as the value of energy production from this source is realized.

The use of stack CEMS in China will grow rapidly. The CEMS market in China will be the largest in the world after 2011. Within China, coal-fired boilers represent the biggest CEMS potential. SEPA (the Chinese equivalent of EPA) is cracking down on SO_2 and NOx emissions from new and existing power plants. The proposed steps include continuous reporting of emissions, which will provide a means for enforcement.

Overall, the world cost for stack and ambient continuous monitoring plus periodic monitoring and other related services will rise to $2.2 billion in 2010. This is a 20% increase over the projected 2009 figures. The rapid expansion in CO_2 measurement investment and the increased activity for stack monitoring in Asia will account for most of the increase. These are the conclusions reached in the latest update of the McIlvaine Air Pollution Monitoring and Sampling World Market report. ■

Edited by Dorothy Lozowski

Author

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

TODAY'S SIS: INTEGRATED YET INDEPENDENT

Bringing process control and instrumented safety systems together while still keeping them separate provides benefits beyond risk reduction

Invensys

FIGURE 1. This image shows the Triconex Safety Instrumented System configuration from Invensys, with triple modular redundant controllers, input/output modules and communications subsystems

By definition, integrated safety instrumented systems (SIS) have the potential to reduce risks. But recent advancement is also enabling the use of more sophisticated instruments and tools that can benefit the process. For these reasons, integrated control and safety systems (ICSS) are receiving recognition across the chemical process industries (CPI).

"There have been developments from a technology point of view that allow the integration of process control and safety systems, yet keep them separate enough so that they don't compromise safety, which was considered an issue in the past," says Kristian Olsson, Safety Center manager with ABB (Norwalk, Conn.). "Keeping the systems separate enables the same risk reduction as would standalone systems, while the integration provides many benefits for the process."

Among the benefits of more integration between process control and SIS for chemical processors is the flexibility it provides. "Especially among our batch customers we see a lot of interest in these integrated systems because if they are running different types of products with different recipes using a batch automation system to manage it all, they need a flexible, safety instrumented system that is able to adjust trip points based on the hazards related to the different chemicals they are using," says Mike Boudreaux, safety instrumented systems brand manager, with Emerson Process Control (Austin, Tex.).

Or, if a processor has different hazard scenarios based on what step they are in a process, an ICSS allows them the flexibility to more aptly handle those hazards.

Integrated, yet separate

While this type of system is obviously designed to keep the process from going out of control while maintaining flexibility, there are many different ways to provide the integration and several different levels of integration. In order for the integrated control and safety systems to reduce risks rather than increase them, experts stress the importance of implementing a system that is "integrated, yet separate."

Several standards, among them IEC 61508 and OSHA-endorsed ISA S84.01, require that the control system shall be separate and independent from the safety related systems. This means that the control and safety system should not share common hardware and configuration tools, for example, to eliminate common cause failures. The systems are integrated, though, when it comes to operator human interface or the sharing of non-safety related information, according to Erik de Groot, global manager for safety systems with Honeywell Process Solutions (Morristown, N.J.).

The simplest way to achieve integration is via an interfaced approach, which would include a Brand X control system and a Brand Y safety system that work well together. In this situation, the two systems share information via a gateway or third-party connection.

On the plus side, today's interfaced approach is better at data sharing than the interfaced systems of the past, allowing the systems to provide more information to operators, which provides the opportunity to diagnose, troubleshoot and prevent risky situations. For processors who are looking for a system that has compatibility, but aren't looking for a new control system, the interfaced approach is a good option. However, potential users need to keep in mind that while an interfaced approach can share important process information, it is somewhat limited in the amount of information and level of detail it can provide.

For companies in need of more information or that are ready to replace their control systems, automation companies can provide process control systems with integrated, yet independent, safety instrumented systems. "The best of these systems are integrated but separate, which means

ABB

FIGURE 2. **ABB's High Integrity safety system, which is paired with its System 800xA for process control, is integrated but separate thanks to "embedded diversity," which means the hardware and software architecture of the controllers is different to ensure that the failure modes of the safety system are completely unique from the potential failure modes of the process control system**

they are born from the same cloth so they play well together, but are still considered separate and independent systems," says Charles Fialkowski, national process safety manager with Siemens Energy & Automation (Spring House, Pa.). "This type of system doesn't have any issues as far as bringing the information together in a common format and there's no gateway or third-party device. Everything is done seamlessly."

It is important not to confuse integrated systems with what is often referred to as "common" systems. The main differentiator between integrated and common systems is that in common systems the same components are used for process control and safety whereas with integrated, but independent systems, a complete physical separation of the safety instrumented system and the process control system is maintained.

However, the way the separation is maintained in an integrated system varies from vendor to vendor. For instance, Emerson Process Control's offering, Delta V SIS, uses completely different hardware and software to do the logic solving than is used in the process control system I/O (input/putput) and controllers. The Delta V SIS has its own safety communication network, meaning it doesn't share the control network communications. It has completely different hardware with a completely different design from the process controllers, as well as a different operating system. Despite the physical separation, operations, engineering and maintenance can use shared components, provided there are no concerns for functional safety.

ABB's High Integrity safety system, which integrates with its System 800xA for process control, is integrated but separate thanks to "embedded diversity," according to Olsson. Here, independence in the performance of the safety system and the process control system is achieved by implementing diversity in the design of the controllers. This means measurements have been taken in design, implementation and testing within the hardware and software architecture of the controllers to ensure that the failure modes of the safety system are completely different than the potential failure modes of the process control system. "This is important because if a failure in the process control system causes a plant upset, we can be certain the safety system will take the proper measurements to bring the process back to a safe state," explains Olsson.

Honeywell handles the integrated but independent challenge in another way. The company provides its Safety Manager safety system as part of the overall Experion Process Knowledge System. Safety Manager integrates seamlessly in the HMI (human-machine interface) and allows peer-to-peer communication with the Experion C300 process controller, although the safety system is completely independent from the control system. In the system architecture, the customer has the option to select the level of integration as it applies to the safety related communication between safety systems. They can choose to make use of the same infrastructure as the Experion system or they can isolate the safety-related communication over a redundant, independent safety communication network. "In either case, the safety integrity level is guaranteed," notes de Groot.

Pros and cons of integration

Benefits of integrated systems such as these are many. For example, many of the tools used for tracking, history, and documentation and reporting of information can be used by both the process control and safety systems. "This gives end users benefits in their every day work in terms of maintenance, engineering and record keeping," notes Olsson. "Record keeping and documentation are especially helpful in the chemical processing industry where an audit trail is important. They can record when a certain setpoint or operation was made or changed in the system and by whom. Then if they need to track an incident or quality issue, they can find the information they need to do this."

Asset management and predictive maintenance tools also can be brought from the process control world into the safety realm to improve availability because users can ensure that equipment is maintained in an effort to prevent problems before there is a process upset or impact on production.

While the benefits are plentiful, there are also a few risks. "When it comes to interoperable and integrated systems there are details that need to be examined like cyber security, which is the ability of the safety system to continue to function even if there is a cyber or network attack," says Joe Scalia, controls systems architect and acting director of the safety business with Invensys Plc. (London, England).

He notes previous instances where a processing facility has had a so-called worm or a disgruntled former employee directly attack the system. "Unfortunately the safety systems didn't have adequate security and were bypassed or turned off," Scalia says. "Think about the amount of risk for chemical processors where most of what they use is toxic or could cause an explosion."

To get around this, Scalia stresses the importance of process control and safety systems being able to share data through integration or interoperability, but that the safety system must have its own link. "It polices that link and has its own capabilities. If something happens to the communications network, the communications function of the safety system is completely separated from the safety system's ability to function."

Invensys' Triconex system has this capability.

Tools of the trade

Security risks aside, the increased use of an ICSS is enabling the use of more sophisticated tools, such as simulations and partial stroke testing. For example, Invensys has an offering where immersive virtual-reality training can be coupled with the simulators from the process control system that works toward simulating a safe process. This allows operators to move through an environment and know what the hazards are and what their responses should be without endangering themselves.

Similarly, Emerson offers offline simulation tools for the process control system that can be integrated with the safety instrumented system to provide a complete offline simulation environment for operator training and also for testing the system to see how they interact together.

If a plant owner wants to bring operators in for training on different abnormal situations that might occur in the process, it can be done offline. This simulation will provide operators with exact experience via operator graphics and interactions so they can see what happens and learn how to handle an emergency shutdown situation or an abnormal situation. "The whole experience for the operator is exactly what they would experience online if they were actually running the chemical process," says Boudreaux. "There are a lot of benefits to this, the biggest being that if they are familiar with abnormal scenarios and know how they've reacted during the simulations, they can think more clearly and respond more swiftly and appropriately during a realtime situation."

Simulations can also be used for

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testing changes that were made to the safety instrumented system. For instance, if an engineer wants to change a trip point or the logic in the safety system module, they can first make that change in an offline environment and run a full functional test. It will operate just as it would in a physical logic solver. "That saves some engineering costs, and because it provides the ability to test every scenario offline, tests can be done much more rigorously," explains Boudreaux.

Integration is also permitting the use of intelligent device communication with partial stroke testing. In the past, there were multiple valves on the safety system to serve as back up in the event of failure of the valve. Typically these valves had to be taken offline for testing periodically. More recently, according to Art Pietrzyk, critical process control and safety segment manager with Rockwell Automation (Milwaukee, Wis.), there's a trend toward using safety-certified instrumentation and safety-certified valves and algorithms that work with the valves to perform partial stroke valve testing. "They put positional and sensing devices on the valve and move it to a partial opening to make sure it's still responding and that the safety integrity of the valves is in order," says Pietrzyk.

Generally this type of testing helps extend proof test intervals to ensure a valve's safety integrity is where it should be. Users of the technology do not have to do proof tests as often if partial stroke testing is performed. Partial stroke testing also provides information and data about valves and process behaviors, as well as allowing predictive maintenance, if needed.

When the safety and process benefits are spelled out and coupled with the ability to use more sophisticated, process- and safety-enhancing tools, integrated safety and control makes sense, especially in an economy when processes are running for longer periods of time between turnarounds. "It is important that the process and safety systems controlling the compressors, turbines and other critical equipment are available to generate money and ensure that the plant continues to run in a safe manner," says Scalia. "The bonus is that users are getting additional functionalities, such as communicating with intelligent devices so they can more effectively maintain and optimize their operations." ■

Joy LePree

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CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Kate Torzewski

Adsorption

Successful adsorber design requires information about certain adsorbent properties, including: adsorbent densities and void fractions; isotherms or other equilibrium data; and data on mass-transfer kinetics and fixed-bed dynamics. Here, these adsorbent properties are explained, along with corresponding equations.

DENSITIES AND VOID FRACTIONS

Three densities are relevant: bulk, particle and solid. There are four pertinent void fractions, three corresponding to the three densities, and one representing the overall void fraction in the bed of adsorbent (ε). These terms are related in the following way:

$$\rho_B = (1-\varepsilon_B)\rho_P = (1-\varepsilon_B)(1-\varepsilon_P)\rho_S = (1-\varepsilon)\rho_S \quad (1)$$

Bulk density is the mass of adsorbent in a given volume. Particle density is the mass of adsorbent per volume occupied by the particle. Solid density is the mass of the adsorbent per volume occupied by the particle, but with the pores' volume deducted.

EQUILIBRIUM DATA

Adsorption-equilibrium data are usually gathered at a fixed temperature and plotted or tabulated as isotherms: adsorbent capacity (loading) versus fluid-phase concentration (or partial pressure, for gases and vapors). Below are three equilibrium equations for isotherm data.

Henry's Law:

$$n^* = AC \quad (2)$$

Langmuir Isotherm:

$$n^* = \frac{AC}{1+BC} \quad (3)$$

Freundlich Isotherm:

$$n^* = AC^B \quad (4)$$

Henry's Law is the simplest isotherm, while the Langmuir Isotherm takes surface coverage into account, and the Freundlich Isotherm is the result of fitting isotherm data to a linear equation on log-log coordinates.

In situations that involve multiple adsorbate components in the feed, the concept of selectivity comes into play. Selectivity, α and β in the three equations below, is the ratio of the capacity of an adsorbent for one component to its capacity for another.

$$\alpha_{ij} = \frac{y_i/y_j}{x_i/x_j} \quad (5)$$

$$\alpha_{ij} = A_i/A_j \quad (6)$$

$$\beta_{ij} = \frac{1+\dfrac{1-\varepsilon}{\varepsilon}A_j}{1+\dfrac{1-\varepsilon}{\varepsilon}A_i} \quad (7)$$

KINETICS DATA

Kinetics data describe the intraparticle mass-transfer resistance and control the cycle time of a fixed-bed adsorption process. Fast kinetics, or a high rate of diffusion, occur when the effluent concentration remains level until the adsorbent is almost saturated, then rises sharply. Slow kinetics, on the other hand, occur when the effluent concentration begins fluctuating soon after adsorption starts. The effect of slow diffusion can be overcome by adding adsorbent at the product end, or by increasing the cycle time. It is also possible to use small particles.

Intraparticle diffusion is characterized by an effective diffusivity D_{eff}, which equals $D_{AB}\varepsilon\rho/\tau$. Dimensionless time is expressed as $D_{eff}t/l^2$, which allows the determination of the fractional change (during adsorption or regeneration), as shown below.

$$F \equiv \frac{C_t - C_0}{C_f - C_0} \approx \left[\frac{6}{\sqrt{\pi}}\left(\frac{D_{eff}t}{l^2}\right)^{1/2} - 3\frac{D_{eff}t}{l^2}\right]_{initial} \approx \left[1-\frac{6}{\pi^2}e^{-\pi D_{eff}t/l^2}\right]_{final} \quad (8)$$

This equation shows that, when searching for an effective adsorbent, it is usually safe to choose one having a large diffusivity, a small diameter, or both.

FIXED-BED DYNAMICS

Interstitial mass transfer in fixed beds, primarily fluid-to-particle transfer, can be related to the fluid, adsorbent and system properties via either of two equations, depending on the value of the system's Reynolds number.

$$\mathrm{Re} = \rho \upsilon_s d_p/\mu \quad (9)$$

For 10<Re<2,500, use Equation (10), where Sc equals $\mu/\rho D_{AB}$.

$$j_D = (k/\upsilon_s)Sc^{0.667} = 1.17\,\mathrm{Re}^{-0.415} \quad (10)$$

For lower flowrates, corresponding to values of a modified Reynolds number, Re', of below 50, use Equation (11).

$$j_D = 0.91\psi \mathrm{Re}'^{-0.51} \quad (11)$$

$$\mathrm{Re}' = \rho \upsilon_s/\mu \quad (11a)$$

NOMENCLATURE

A	Henry's law coefficient
B	empirical coefficient
C	Concentration (subscripts: 0, initial; f, final; i, instantaneous)
d_p	particle diameter
D_{AB}	adsorbate diffusivity in the liquid
D_{eff}	effective diffusivity
F	fractional conversion
i	assigned to strongly adsorbed component
j	assigned to less strongly adsorbed component
j_D	Colburn-Chilton j-factor
k	fluid-to-particle mass transfer coefficient
l	particle radius (for a sphere or cylinder), or half-thickness (for a rectangular solid)
L	bed length
n^*	adsorbent loading
Re	Reynolds number
Sc	Schmidt number
t	elapsed time
x_i	mole fraction in fluid phase
y_i	mole fraction in adsorbed phase
α	selectivity, 1<α<infinity
β	selectivity, 0<β<1
ε	void fraction (subscripts: B, bulk; P, particle; S, solid)
μ	fluid viscosity
ρ	fluid density (subscripts: B, bulk; P, particle; S, solid)
τ	tortuosity
υ_s	superficial velocity
ψ	particle shape factor

The particle shape factor, ψ, is 1.0 for beads, 0.91 for pellets and 0.86 for flakes. α_i is the ratio of particle interfacial area to volume, which equals $6(1-\varepsilon)d_P$.

Another major factor in bed dynamics is pressure drop. Most adsorbers are designed to operate with relatively low pressure drop, because large particles are used whenever possible and the velocity is typically low, to allow equilibration of the fluid with the adsorbent. The pressure drop in a fixed bed is represented by the Ergun Equation, below.

$$\frac{\Delta P}{L} = \left(150\frac{1-\varepsilon_B}{\mathrm{Re}} + 175\right)\left(\frac{\rho\upsilon_s^2}{g_c d_p}\frac{1-\varepsilon_B}{\varepsilon_B^3}\right) \quad (12)$$

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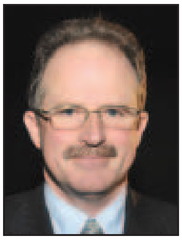
WHO'S WHO


Brandmeier


Mueller


Shott


Hook


Lee

Michael Brandmeier becomes senior vice-president of **Toray Plastics (America) Inc.** (North Kingstown, R.I.) and joins its board of directors.

Codexis, Inc. (Redwood City, Calif.) promotes *David Anton* to senior vice-president, research and development, and *John Grate* to senior vice-president, science and innovation, and chief science officer.

Frank Mueller, president of **Kaeser Compressors , Inc.** (Fredericksburg, Va.) is named to a two-year term as president of the Compressed Air and Gas Institute (Cleveland, Ohio).

Nick Phillips becomes global business development director of **Clariant Oil Services** (Charlotte, N.C.).

Pieter Schoehuijs becomes chief information officer for **AkzoNobel NV** (Amsterdam).

Ian Shott, CEO of **Excelsyn Ltd.** (Newcastle, U.K.) becomes president of the Institution of Chemical Engineers (IChemE; London).

Veolia Water Solutions & Technologies (Birmingham, U.K.) names *Stuart Lee* director of engineered solutions, and *Bob Hook* general manager of design & build.

WIKA Instrument Corp. (Lawrenceville, Ga.) promotes *James Zielinski* to director of customer operations.

Bill Harvey becomes the director of logistics engineering for **ChemLogix LLC** (Blue Bell, Pa.). ■

Suzanne Shelley

AUGUST

New Products

Mettler Toledo

Metso


Hoerbiger Kompressortechnik Holding

Coriolis meters for low-flow applications

The Micro Motion Elite Coriolis meter range (photo) has been expanded for low-flow applications. Available in two sizes (2 and 4 mm nominal dia.), the new meters deliver flowrates of 2 to 330 kg/h with accuracies of ±0.05% (liquid flow), ±0.35% (gas flow), and ±0.0000 g/mL (liquid density). Wetted parts are of 316L stainless steel and the sensor enclosure is available with a polished 316L external surface and rounded corners. For corrosive and high-pressure applications, the meters are also available in nickel alloy construction and are rated to 413 bar. — *Emerson Process Management, Hatfield, Pa.*
www.emersonprocess.com


Emerson Process Management

Test pH, conductivity, dissolved oxygen and ion concentrations

These multi-parameter portable meters (photo) measure pH, conductivity, dissolved-oxygen and ion concentration. All three instruments are based on the rugged design of SevenGo, and are watertight according to IP67. The three new meters expand the range of portable instruments and offer innovative Intelligent Sensor Management. The SG23 is a robust, dual-channel pH/conductivity meter for routine work. The professional pH/ion/conductivity meter SG78 combines all functions of pH and conductivity measurement with a full-fledged ion mode. The multi-parameter SG68 covers the measures pH/ion/dissolved oxygen. Handy features like automatic air-pressure compensation, helpful ion mode, and a wireless infrared communication port, save time and guarantee correct results. — *Mettler Toledo, Columbus, Ohio*
www.mt.com

Condition monitoring & analysis integrated in automation system

This company has integrated machinery condition-analysis technology into the metsoDNA CR automation system. The application, called DNAmachineAssessor, enables maintenance staff to have first-hand access to machine vibration data and mechanical component condition analysis through the same user interface (photo), which is used to measure and control the process and product quality. New metsoDNA CR system features have been developed to enable high-frequency I/O and digital signal processing. — *Metso Corp., Automation business line, Helsinki, Finland*
www.metso.com

An optimum valve for reciprocating pumps

The CL pump valve (photo) for reciprocating pumps combines the two key factors for cutting operating costs in one valve: optimum performance and efficient service. The CL pump valve has an optimized design and a combination of proven materials. They can be incorporated into any reciprocating pump and are suitable for use with any aqueous solution. The valve features heavy duty, non-metallic sealing elements, springs that do not come in contact with the medium being handled, and optimized flow control. — *Hoerbiger Kompressortechnik Holding GmbH, Vienna, Austria*
www.hoerbiger.com

This range of flowmeters and controllers is now more flexible

The Smart-Trak 2 (photo, p. 24D-2) is a significant redesign of this firm's flagship Series 100 Digital Mass Flow Meters and Controllers. Among the expanded functionality of Smart-Trak 2 is true linear performance, which provides high accuracy and great flexibility in multiple gases. With Dial-A-Gas Technology, users select from up

Note: For more information, circle the 3-digit number on p. 54, or use the website designation.

to ten pre-programmed gases, or substitute their own. Smart-Trak 2 also provides the ability to adjust calibration in the field for each of these ten gases independently. It provides the most advanced linear sensor available, smoother valve performance, more robust electronics and more control over a wide range of functions, according to the firm. The Compod, has also been introduced as a Smart-Trak 2 add-on, which expands networking, streamlines and simplifies functionality, and reduces costs. — *Sierra Instruments, Monterey, Calif.*
www.sierrainstruments.com

Sierra Instruments

Moyno


This pump provides precise control in low-flow applications

The Chemical Metering Pump (photo) offers economical and efficient performance when metering low-flow liquids in a wide range of processing applications, including dosing, sampling and metering. The progressing cavity design of the pump results in a smooth flow, free from pulsations and variations in velocity and volume, which prevents material waste or mixture imbalance. The pump features sealed universal joints for longer life, and has no valves to clog, stick or vapor lock. The unit provides pressures to 300 psi and flowrates from 1 to 190 gal/h. The pump is available in bare-shaft, close-coupled, and motorized configurations. — *Moyno, Inc., Springfield, Ohio*
www.moyno.com

An aseptic valve for critical areas

This patented, compact aseptic control valve (photo, p. 24D-3) newly added to the Badger Meter valve range, is suitable for use in critical areas, such as bioreactors pharmaceuticals, biologics and food processing. The Series SCV-09 is a modulating diaphragm style valve that meets the manufacturing standards of 3A Sanitary Standards. The valve uses a patented sealing arrangement, which avoids metal-to-metal contact that could re-

GEA Niro

Pump Engineering

Colder Products

sult in metal particles being released into sensitive products, while providing a similar level of control to a metal plug and seat. The valve is available in sizes 1/2, 3/4 and 1 in. with body of 316L stainless steel. It is suitable for low to medium flowrates and has a maximum operating pressure of 10 bar. — *Pump Engineering Ltd., Littlehampton, U.K.*
www.pumpeng.co.uk

A new spray dryer for laboratories

The MobileMinor Basic spray dryer (photo) is said to meet all the basic requirements of laboratories, especially those in small companies and universities, and other laboratories that don't need many of the options available for the advanced MobileMinor models. The MobileMinor Basic meets all health and safety requirements, including dust explosion hazard (class ST1), and is easy to operate. The system is suitable for laboratories that need only basic facilities for drying food and chemical products. It is supplied with a push-button control panel and either a rotary atomizer or a co-current two-fluid nozzle for atomization. A single-point powder discharge makes product collection easy, and the standard cyclone secures an efficient product recovery. A cartridge filter is available (optional) for cleaning the exhaust gas to reduce emissions to a minimum. — *GEA Niro A/S, Søborg, Denmark*
www.niro.com

Download CAD drawings for free

This company is complementing its comprehensive product database with an easy-to-use download tool for two- and three-dimensional CAD drawings. The software enables users to generate and download CAD files for sensor, fieldbus, interface and connectivity products free of charge and without registration. System-specific and cross-system formats are possible for technical documentation purposes or 3D models for more complex Solidworks applications. — *Turck, Inc, Minneapolis, Minn.*
www.turck.com

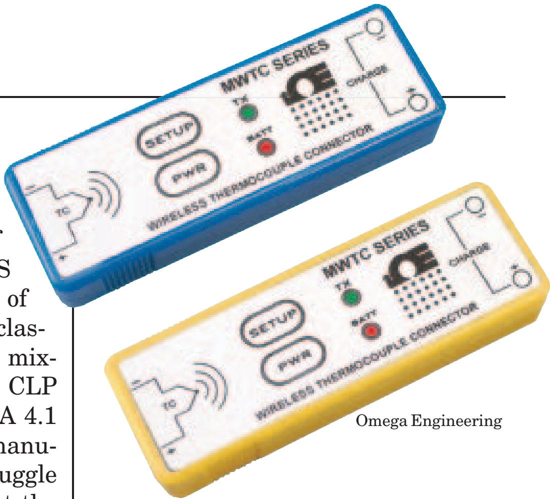
For clean applications, use this metal-free

The all-plastic DrumQuik PUR chemical-dispensing system (photo) provides extraction of high-purity chemicals from drums, jerry cans and intermediate bulk containers. The system is comprised of a PVDF coupler and an HDPE drum insert assembly. The drum insert assembly contains a bung closure and dip-tube and can be shipped as part of a drum package, providing a cost-efficient alternative to open and semi-open dispensing systems. The coupler features a built-in

vent port, which allows connection of a check valve to prevent release of harmful vapors to the atmosphere or an inert blanket gas (N_2 or CO_2) to protect valuable chemicals from exposure to air. DrumQuik PUR is made from FDA-approved, animal-free and RoHS-compliant materials that are compatible with high-purity chemical handling processes found in semiconductor, flat panel and pharmaceutical manufacturing. — *Colder Products Co., St. Paul, Minn.*
www.colder.com

Support EU regulations for classification, labeling and packaging
Intelligent Authoring's (IA) Service Pack 2 (SP2) is now available, with support for the EU's new Regulation on Classification, Labeling and Packaging (CLP) of substances and mixtures. This solution now provides Managed Regulatory Content in support of the new regulation, enabling users to fully automate the creation of CLP-compliant labels and SDS documentation. The deadlines of December 1, 2010 for substance classification and June 1, 2015 for mixtures provide little time for full CLP compliance, but the delivery of IA 4.1 SP2 facilitates this process for manufacturers that may otherwise struggle to meet these deadlines. Being at the forefront of changing regulations, this firm will continue to track the GHS schedule and will add support as additional countries announce their adoption plans. — *Atrion International, St. Laurent, Quebec, Canada*
www.atrionintl.com

A thermocouple connector that communicates wirelessly
The MWCT Wireless Smart Thermocouple Connector Series (photo) features stand-alone, battery-powered thermocouple (TC) connectors that transmit measurement data back to a mating receiver up to 90 m away. Each unit is factory set as a Type J, K, T, E, R, S, B, C or N calibration connector. When activated, the connector will transmit readings continuously at a preset time interval that was programmed by the user. Each unit measures and transmits: TC input reading and connector ambient temperature to a receiver and is displayed on the PC screen in real time using free software. — *Omega Engineering, Inc., Stamford, Conn.*
www.omega.com ■



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Cover Story

Fine Grinding With Impact Mills

A primer on which mill to use for various types of products

Bodo Furchner, Hosokawa Alpine AG

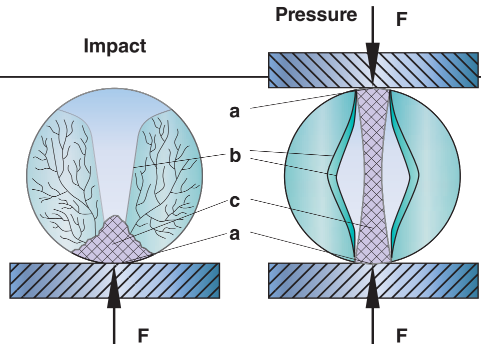

FIGURE 1. Fragmentation of glass beads is achieved by either impact or pressure (F = force; a = contact area; b = cracks; c = fines)

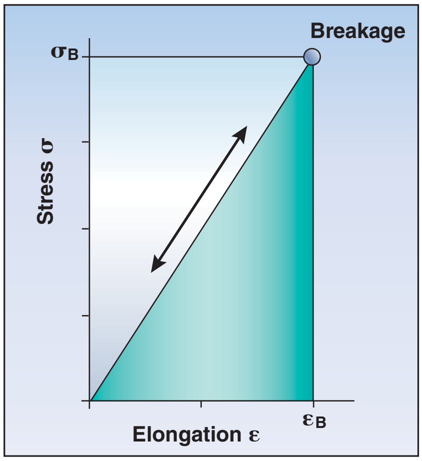

FIGURE 2. This stress-strain curve shows the behavior of brittle-elastic materials

Many branches of the chemical process industries (CPI) make use of impact comminution to process solid matter, such as minerals, foodstuffs, pharmaceutical products, and above all, products for the chemicals industry. Impact comminution is also used for coarse crushing, but the focus of this article is fine grinding with end-product particle sizes below 500 µm. The technology of impact comminution is, however, not particularly popular with the users of impact grinding systems because it is energy-intensive, associated with a high noise level and frequently also gives rise to time-consuming maintenance work. In spite of this, impact comminution is still the most cost-effective solution in many processing operations.

The fundamentals

With every method of comminution, one has to generate a level of stress in the particles that is so high that the particles fracture as a result. Beside other methods, this stress can be generated by pressure (compression) or impact (Figure 1). In the case of compression, the particle is stressed between two solid elements, whereas in the case of impact comminution, the particle is in contact with only one other element at the moment of fracture, either an impact plate or another particle.

A prerequisite for impact comminution is brittle-elastic material behavior. Materials scientists call a material brittle-elastic if deformation of the sample is initially proportional to the applied stress and the fracture occurs suddenly (Figure 2). The dark area under the plotted line is equivalent to the work that is necessary to deform the particle. With impact comminution, the kinetic energy of the particles is employed to generate the requisite degree of deformation. In the linear range, the deformation is elastic and reversible. As soon as higher stresses occur, the material strength is exceeded locally and cracks are triggered. The cracks grow extremely quickly and lead to destruction of the particle.

Equipment has been built for scientific experiments in which individual particles are subjected to one single impact under defined conditions. From these single-particle impact tests the following three things are known: that a minimum fracture energy must be applied to the particles, that the probability of fracture is dependent on the kinetic energy and that the resultant particle-size distribution is dependent on the properties of the material being processed.

According to theory, a speed multiplication of 5.6 would be necessary to double the stress in the particles. In other words, increasing the impact speed has only a limited influence on the expected fineness. On the other hand, the impact speed is the only parameter with which it is possible to effectively change the stress condition in a particle, which is why impact mills usually run at high peripheral speeds of up to 150 m/s. When two rotors are driven to rotate in opposite directions, relative speeds of up to 250 m/s can be achieved. In jet mills, compressed gas is expanded in Laval nozzles. At common gas pressures and temperatures, the exit velocity of the gas jets is around 500 m/s.

As Figure 1 shows, a single fracture event leads to a number of coarse fragments but to relatively little fine product. Because of this, the aim is multiple stressing of the particles in mills in order to obtain a fine end product. One can assume that a feed material is subjected to between 5 and 20 impact events in simple rotor impact mills. With fine grinding, air classifiers can be integrated into mills that allow only those particles with the desired end-particle size to pass through the classifying wheel, but which return coarser particles for final grinding. For jet mills, up to 100 stressing events can be necessary to grind the feed material to high fineness values if it is of poor grindability. The number of stressing events is therefore a parameter that has a greater influence on the product fineness than the stressing speed.

The particle size distribution of the ground product is a function of the mill parameters, stressing frequency and

TABLE 1. MOHS' SCALE OF HARDNESS	
1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Orthoclase
7	Quartz
8	Topaz
9	Corundum
10	Diamond

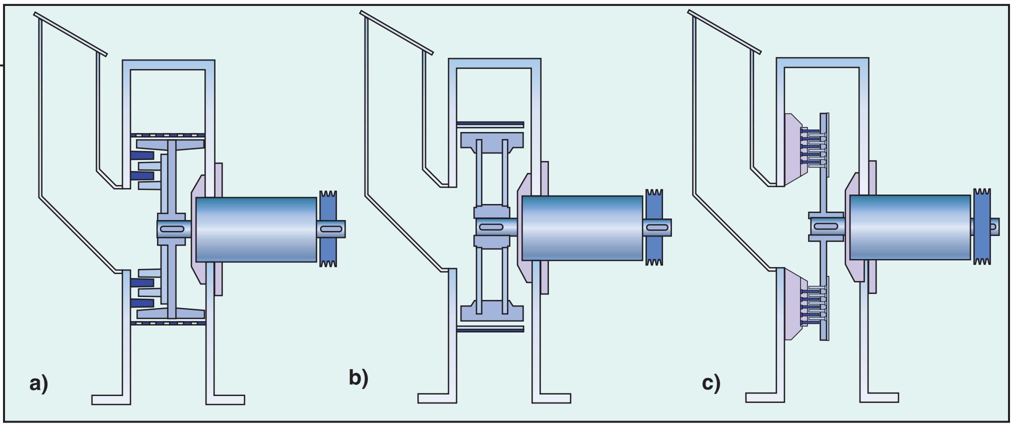

FIGURE 3. Simple rotor impact mills with crushing rotor and sieve (a), with plate beater unit and grinding track (b) and with pin discs (c)

stressing intensity, as well as the feed material characteristics. Today it is not possible to accurately predict the result of a comminution trial with an impact mill based on scientific principles. This applies to particle size distributions and to the specific grinding energy.

Feed material requirements

If impact comminution is to be economically viable, the feed material must fulfill a number of general requirements. In the case of fine impact mills, there is a maximum feed size that must not be exceeded if the mill is to remain undamaged by any large lumps in view of the high peripheral speed. A particle size of 5 to 10 mm can be assumed as the maximum, whereby the faster the rotor rotates, the finer the feed material should be. Tramp material must be removed from the feed material.

Mechanical impact grinding can be used on materials with a Mohs' hardness of up to 3–4 (see Table 1). But even small amounts of harder components in the feed material can lead to an uneconomical degree of wear. When grinding natural gypsum — which is actually soft — a few percent of quartz in the feed will make it necessary to exchange the wear plates in the mill frequently. The same or similar phenomenon applies to vegetable products that are contaminated with sand. In the case of especially fine feed materials, harder materials can also be processed, provided that the wear protection in the mill is well adapted to the product properties.

The feed material should not be heat-sensitive, that is, the softening or melting point has to be above 70°C if the material is to be ground in a mechanical impact mill. The reason is that the energy of the motor is converted almost completely into heat, and mills and systems heat up to 50–60°C under full load. Heat-sensitive products can be processed only by cooling the feed material or the mill air, or both, which ultimately means additional energy costs.

Liquid components in the feed material can also have an extremely disruptive effect. The product should be dry, with the maximum moisture content of normally only a few percent. If liquid is released during comminution, this frequently leads to the formation of build-up. This also applies to feed material that contains oil or fat.

Besides the specifications related to the particle size distribution, the product properties mentioned here play a major role in the selection and design of impact mills. For this reason, trials are always carried out with a test system for new applications.

Machine types for fine grinding

Rotor impact mills have been in use for over 100 years. As a result of the wide range of feed products, a great number of different machine types have established themselves on the market during this time. Jet mills, which operate with a gaseous medium, have also been on the market for a long time. In this article, only a few of the widely available machine types can be described.

Mechanical impact mills. Simple impact mills consist essentially of a high-speed rotor. Fine particles follow the flow of air in the mill after extremely short acceleration paths. Because of this, the clearance between rotating and stationary grinding elements should only be a few millimeters. Characteristic for fine impact mills are a high-speed rotor and stationary grinding elements located in its immediate proximity. The grinding zone can be disc-shaped, in which case the product is fed centrally and the feed material migrates in radial direction across the disc, just as with the pin mill. The grinding zone can also be cylindrical, in which case the feed material migrates along the cylindrical surface through the mill. The transport of the material can take place against the force of gravity, in the direction of the force of gravity, or even at right angles to it. In addition, impact mills can be equipped with a classifying discharge, for example sieves, screens or classifying wheels. The design most suitable for a given application must be determined during the course of trials.

Classic rotor impact mill. These machines are characterized by a flat-cylindrical, vertically upright housing and a horizontal shaft supporting the rotor (Figure 3). These machines have a big door, which can be easily opened for maintenance of the grinding equipment. The product is fed to the center of the rotor and exits in ground condition at the periphery of the mill. Air flowing through the mill assists transport of the product and cools the machine and product. The high-speed rotor with impact elements grinds the feed material and assists the transport of the air, in a similar way to a radial fan. The fineness is set as a function of the rotor speed and the product throughput. Higher throughputs lead to a coarser product, which is attributed to increasingly ineffective particle-particle impacts. The feed metering unit is controlled by the current loading of the mill motor.

Sieve inserts with various kinds and arrangement of perforations have the benefit of top-size control, but are always more prone to wear. Sieves can only be employed down to a minimum aperture size of approximately 0.5 mm. The design shown in Figure 3a is therefore suitable for coarser grinding tasks. In the fine range and with coarse feed materials, grinding tracks are used. Grinding tracks usually have an annular discharge gap for the ground product. In the case of the plate beater unit (Figure 3b), exchangeable impact plates permit the processing of mildly abrasive materials. At high speeds and low throughputs and in combination with a grinding track, fine products are achieved. When employed in combination with a grinding track or sieve ring, or both, the plate beater unit is suitable for fine grinding, defibration, chipping and deglomeration.

With pin discs (Figure 3c), comminution takes place between the rotating and stationary concentric rows of pins. The diameter of the pins and the pitch diameter for the pins are geared to each other such that particles cannot flood through the pin rows. The fineness is regulated as a function of the speed. The principle of multiple stressing is implemented in this mill in an extremely graphic manner: the particles have to pass through every row of pins before they are able to exit the mill and impact against many pins in the grinding process. The narrow gap between the rows of pins ensures high impact speeds, even for fine particles. Tramp material in the feed material is a risk to the relatively fragile pins and can cause a lot of damage.

The largest mills of this type have rotor diameters of some 1.5 m and a drive power of up to 315 kW. The maximum peripheral speeds reach 150 m/s. The maximum fineness that can be expected for simple impact mills is, for many products, around 100 µm. When reference is made in this article to the product fineness but is otherwise not specified, this is understood as the cumulative undersize of the particle size distribution of 97%. Table 2 shows some applications for simple impact mills.

Pin mills with two rotating pin discs (disintegrators). The basic design of this machine corresponds to that of the classic, fine impact mill, although here, both pin discs are driven separately (Figure 4). The fineness of the end product is set as a function of the peripheral speeds of the counter- or co-rotating pin discs. The relative speed of the outside row of pins can reach up to 250 m/s. Compared with the simple, fine impact mill, the counter-rotating pin mill achieves significantly higher fineness.

The use of two rotating discs reduces the formation of deposits on the pins in comparison with pin mills equipped with one stationary disc or mills with grinding tracks. This can be accomplished by a generously dimensioned housing, the so-called wide-chamber housing. Therefore, this machine is especially suitable for the grinding of sticky feed material. Applications for this machine type are given in Table 3. The largest pin mill of this type ever to be built has a pin disc diameter of approximately 1.1 m and a drive power of 500 kW.

Long gap mills. In contrast to the classic, fine impact mill, the rotor here is vertically arranged (Figure 5). The feed material is charged from below, entrained in the transport air and is conveyed pneumatically through the grinding zone, but can also be fed to the lower area of the grinding zone. The grinding zone extends over the entire cylindrical area between the rotor beaters and the peripheral grinding track. The product must travel all the way along this gap, which is longer compared with other mills. Mills of this type are therefore called long gap mills, although the name air vortex mill is also known. This name, however, implies that comminution is the result of particle-particle impacts in an air vortex. Because an efficient fine-grinding operation necessitates unhindered impact of the particles on the grinding elements of the mill, grinding in air vortices can only be a minor effect. The fineness in this mill

TABLE 2. APPLICATIONS FOR SIMPLE ROTOR IMPACT MILLS

Pharma/Food	Chemicals	Minerals	Other
Sugar	Fertilizer	Natural gypsum	Wood shavings
Lactose	Paint	FGD-gypsum	Cork
Casein	Pigments	Limestone	Fodder
Herbal tea	Salts	Chalk	Recycling
Starch	Silicates		Used paper
Gelatine	Wax		Tobacco
Spices	Resin		
Hibiscus	Stearate		
Sage	Sulfates		
Rose hips	Phosphates		
Active pharmaceutical ingredients (API)	Plastics		
	Cellulose derivatives		

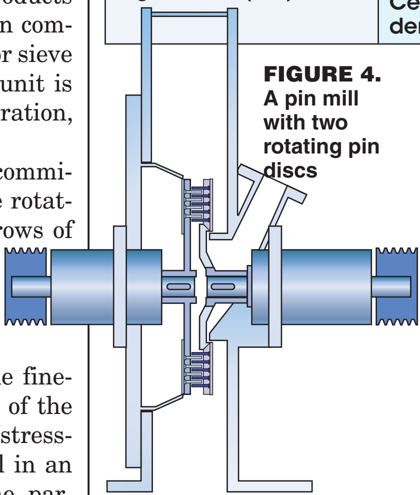

FIGURE 4. A pin mill with two rotating pin discs

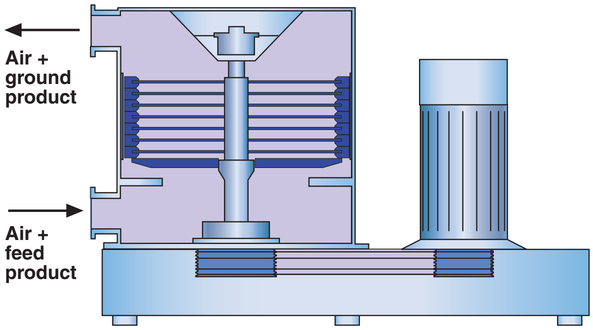

FIGURE 5. In long gap mills, the rotor is vertically arranged

TABLE 3. APPLICATIONS FOR PIN MILLS WITH TWO ROTORS

Pharma/Food	Chemicals	Minerals	Other
Spices (cryogenic grinding) Cacao press cakes	Paints Pigments Stearate Plastics (cryogenic grinding)	Chalk Limestone Coating of limestone	Proteins Rubber (cryogenic grinding)

TABLE 4: APPLICATIONS FOR THE LONG GAP MILL				
	Food	**Chemicals**	**Minerals**	**Other**
Fine grinding	Cereals Vegetables Soya Fish meal Starch Fiber Bran Thickener	Pigments Paints Carbon black Titanium dioxide Plastics Iron oxide	Gypsum Coating of limestone	Wood PVC Rubber Polyurethane foam
Impact drying	Proteins Starch Lactose Casein	Cellulose derivatives Titanium dioxide Pigment suspensions Press cakes	PCC (precipitated calcium carbonate) suspensions Gypsum Aluminium oxide	Blood products PVC filter cakes

TABLE 5: APPLICATIONS FOR CLASSIFIER MILLS			
Pharma/Food	**Chemicals**	**Minerals**	**Other**
Cacao press cakes Sugar Lactose Vegetable products Gelatine Alginate	Powder coating Paints Pigments Silica Resins Wax PVC	Limestone Talc	Proteins Wood Sodium bicarbonate

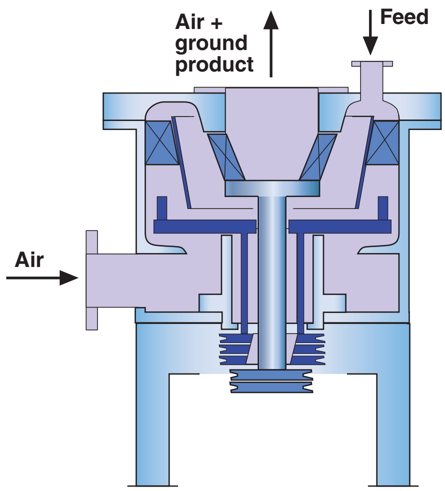

FIGURE 6. Classifier mills achieve the highest fineness among mechanical impact mills

is also set by the rotor speed and the throughput of the feed material.

The rotor of the long gap mill consists of grinding stages located one on top of the other and separated from each other by discs. Each grinding stage is equipped with a number of impact plates. Exchanging the many impact plates is time-consuming, which is why machines are now available that are equipped with continuous impact bars that can be exchanged easily. The rotor is surrounded by the grinding track, which is composed of grooved grinding track segments. An air classifier can be installed above the grinding zone. The classifier, however, does not make a real classifier mill out of the long gap mill, because the recirculation of the coarse material upstream of the grinding zone is complicated.

The long gap mill is especially suitable for simultaneous grinding and drying. (Further applications are given in Table 4.) This is due to the fact that there are no dead zones in which the moist product could cake and deposit. Long gap mills are operated at peripheral speeds of up to 150 m/s, and can grind finer than the simple impact mill as a result of the higher number of stressing events. They can also produce steeper particle size distributions as a result of a narrow residence time distribution. The largest mills of this type have rotor diameters of over 2 m and a drive power of over 1,000 kW. Large long gap mills are by far the largest fine impact mills.

Fine impact mills with air classifiers. Because the grinding elements and an air classifier are integrated into a single machine housing, this type of mill is known as a classifier mill. With classifier mills it is the integrated classifier that controls the product fineness and not the speed of the grinding rotor. Classifier mills thus offer the advantage of the highest finenesses among the mechanical impact mills and stable product properties even if the properties of the feed material are changing. These reasons are the motivator behind the increasing use of classifier mills. However, these advantages give rise to higher costs because a more powerful fan is needed than with the simple rotor-impact mills. The fan sucks the transport air through the mill against the resistance of the classifying wheel. The pressure drop at the classifying wheel can be several thousand Pascals. The feed rate is usually controlled with the current of the mill motor.

A schematic of the most-widespread classifier mill is shown in Figure 6. The maximum peripheral speed of these mills is up to 150 m/s; the air classifiers run at peripheral speeds of up to 60 m/s. This mill type has been on the market since about 1970 and is built in over 20 machine sizes. The largest mills have a drive power of up to 500 kW.

The grinding disc is driven from below via a hollow shaft. The shaft for the conical deflector classifying wheel, which has its own frequency-controlled drive, runs through the hollow shaft. The feed material is charged pneumatically, for which a partial flow of the mill air has to be branched off. Comminuted material follows the flow of air around the guide cone to the classifying wheel. The high-speed classifying wheel allows only fines to pass through it; coarse material is rejected and returned to the grinding disc where it is reground. The cover for the machine can be hinged back so that internals are easily accessible for cleaning.

Dictated by their function, deflector wheels cannot be set to any coarse value desired, but are limited to a top value of around 200 µm (assuming a feed material with a bulk density of 2,000 kg/m^3). At high speeds, classifier mills compete with jet mills, and at coarser fineness values, also with pin mills. Compared with jet mills, the energy consumption of the classifier mill is comparatively low, and compared with pin mills, it has advantages in terms of operating stability, an exact top cut and a higher resistance to wear. Over the course of the years, a number of different classifier mills have been developed, each of which have their strengths for certain applications (Table 5).

Jet mills. In combination with an air classifier, jet mills deliver the highest finenesses as a result of the high impact speed and multiple stressing of the feed material.

Jet mills use the effect that compressed gas is accelerated to extremely high speeds when it is expanded in a nozzle. Thereby, the energy contained in the compressed gas in the form of

TABLE 6: APPLICATIONS FOR THE FLUIDIZED-BED OPPOSED JET MILL

Cool grinding	Delamination / deglomeration	Hard material	Contamination-free processing	Other
Toner Powder coating Wax Plant protectors Paints	Mica Talc Ceramic pigments Pigments Tungsten carbide	Abrasives Technical Ceramics Perlite Glass frits	Dental ceramics Fluorescent powders Silica gel Pharma auxiliaries Acive pharmaceutical ingredients (API)	Silica Flame retardants Rare-earth-magnet materials PTFE Graphite

heat is converted to kinetic energy. The gas can even be accelerated to supersonic speed in a Laval nozzle. A Laval nozzle is characterized by its hourglass shape, which widens downstream of the narrowest diameter in a similar way to Venturis.

Compressed air at 20°C and between 6 and 8 bar overpressure is frequently used, in which case the exit velocity of the air is approximately 500 m/s. If the product permits, the compressed air is not cooled downstream of the compressor, and jet mills are operated at elevated temperatures. Air velocities of approximately 600 m/s can be achieved in this way. After exiting the nozzle, the speed of the jet drops rapidly as a result of air and product being sucked in from the surroundings.

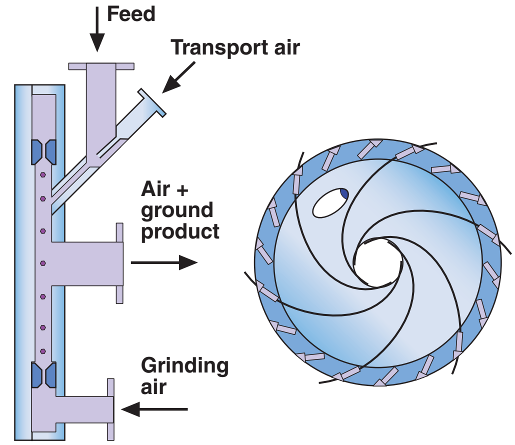

FIGURE 7. The spiral jet mill is relatively simple

If superheated steam is used as the propellant, it is possible to achieve speeds of over 1,000 m/s. A significant disadvantage of grinding with steam, however, is the tricky operation of a system where the risk of condensation in the downstream filter is high. This is the reason why more and more jet mill owners have meanwhile switched from steam operation to compressed air mode.

Increasing demands on the product quality and the development of the fluidized-bed opposed jet mill (described below) have helped jet milling gain acceptance, even though the energy consumption of jet mills is extremely high. Besides taking a look at the fluidized-bed opposed jet mill, the spiral jet mill, which continues to be popular in the pharmaceuticals industry is also considered.

Spiral jet mill. The spiral jet mill is a simple piece of equipment. At the periphery of the flat-cylindrical grinding-classifying chamber, compressed air is expanded in nozzles that are pitched at an angle of between 30 and 50 deg. to the radius (Figure 7). This causes a rotating air stream in the grinding chamber. The feed material, charged to the grinding chamber through an injector, becomes caught up in the rotating flow of air, is centrifuged and ultimately forms a rotating ring of material at the periphery. This transports the feed material into the jets of grinding air, where it is comminuted mainly as the result of impacts between the particles traveling at different speeds. The air stream in the grinding chamber effects a spiral classification: fine material is conveyed to the central discharge opening, whereas coarse material is centrifuged back out to the periphery. A high pressure builds up in the mill as a result of the air rotating at high speed. This makes it necessary to use an injector operated with compressed air to feed the material; with approximately 30%, the injector requires a considerable share of the total air flow.

The spiral jet mill has no fineness control. At a constant air flowrate, the feedrate is the main parameter used to adjust the fineness. A high throughput results in coarse product because the spiral is decelerated, and this leads to a coarser classification.

The advantages of the spiral jet mill — simple design, simple cleaning [(clean-in-place (CIP) capable] and simple sterilization [sterilize-in-place (SIP) capable] — have all combined to ensure that this machine has remained the standard machine in the pharmaceutical industry for fine grinding. And this is in spite of the disadvantages: high noise level in operation (injector), additional gas requirement for the injector, sensitivity to wear, and no fineness adjustment. Spiral jet mills are employed in the chemicals industry for the dispersion of pigments. During a dispersion process, the final particle size is dictated more by the primary particle size in the feed material than by the air classification. Large mills have a diameter of the grinding chamber of approximately 1 m and consume up to 3,000 m^3/h of compressed air. Small mills for product development have diameters of only 30 mm.

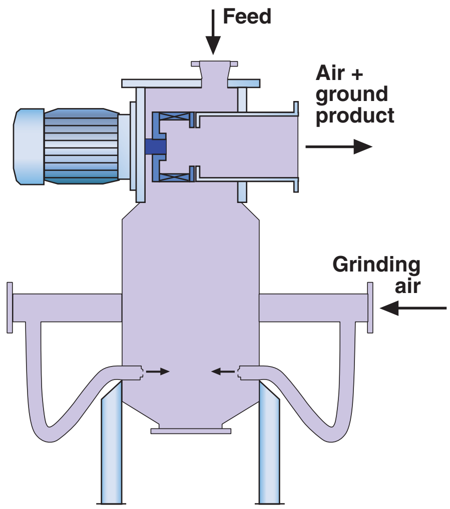

FIGURE 8. This fluidized-bed opposed-jet mill has an integrated deflector-wheel classifier

Fluidized-bed jet mills. The fluidized-bed opposed-jet mill came onto the market around 1980. The big advantage of this jet mill, when compared with the spiral jet mill, is the integrated deflector-wheel classifier, which, together with the constant air flowrate, ensures an extremely constant product quality.

The nozzles expand the compressed grinding air horizontally in the grinding chamber (Figure 8). In the case of frequent product change — that is, the desire to completely empty the vessel — additional bin floor nozzles can also be used. The nozzle diameters range from 1 mm with the small mills to 30 mm with the largest ones. The rising flow of air transports ground product to the integrated classifying

EXAMPLES FOR ENDPRODUCT FINENESS

Figure 9 uses the example of grinding sugar in a pin mill to show that a parallel shift of the particle size distribution is achieved by changing the speed of the pin disc and by changing the feedrate. The highest fineness of 99% < 90 µm is achieved at the highest speed and the lowest feedrate.

In the example shown in Figure 10, the same feed material was used for all machines, namely marble with a particle size of between 0.1 and 2 mm. In each case, the finest particle size distribution produced in the tests with the specified mill type is shown. In the coarser range, one can see that the particle size distribution merely makes a parallel shift. In the fine range, it is not possible to achieve more than 10% under 1 µm; this is due to the integrated classification and the high internal circulation factors.

The energy consumption increases strongly with increasing fineness, which means that for a given system the capacity drops with increasing fineness. Figure 11 shows the energy consumption versus the median particle size for the same feed material as in Figure 10. The power consumption of the mill only is considered, without classifier, fan and other auxiliary units. With the jet mill, the jet power was used for the calculation, and not the drive power of the compressor. In the range of median finenesses between 10 and 100 µm, the specific grinding energy is around 10 kWh/m.t. (m.t. = metric ton). For the highest fineness, the energy consumption goes up to around 1,000 kWh/m.t. There are only few products with a corresponding value-added factor allowing such a high effort for the size reduction. (Marble is not among these products, it is just used as an example here.) ❑

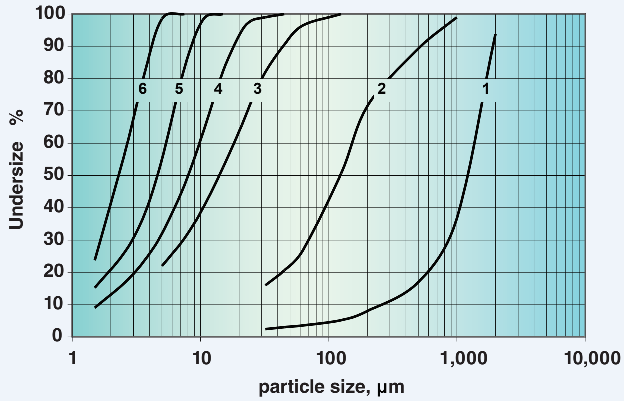

FIGURE 10. The particle size distributions for marble achieved in different mill types. (1) feed material; (2) impact mill with crushing disk (Figure 3a); (3) impact mill with plate beater (Figure 3b); (4) double rotor pin mill; (5) classifier mill; (6) fluidized-bed jet mill

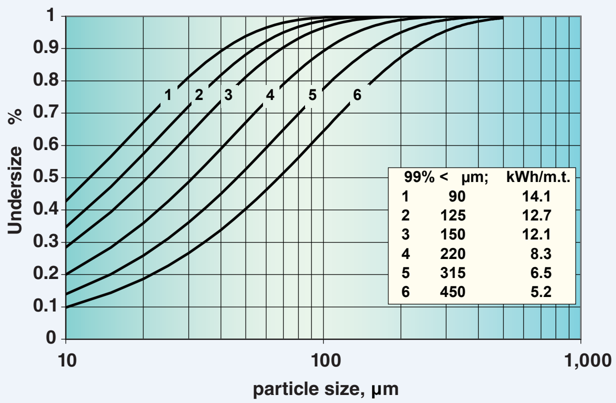

FIGURE 9. The particle size distributions for sugar grinding with a pin mill

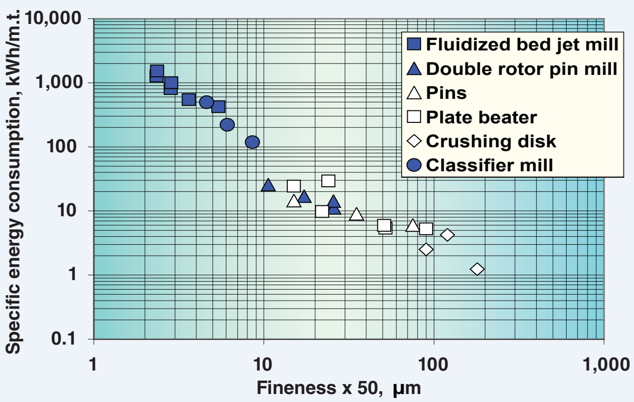

FIGURE 11. Specific energy consumption for grinding marble in different mill types

wheel. Fines are able to pass through the classifying wheel, whereas coarse material is rejected and falls back into the grinding zone. To ensure that a constant material level is maintained, the metering unit is controlled by the power consumption of the classifier drive or the weight of the filled mill.

Grinding takes place both in the individual jets themselves and in the focal point of the jets. The gas jets introduced into the particle bed fluidize the product and draw individual particles into the jets. Fine and light particles are accelerated and blasted away at the circumference of the jet and cannot enter into the center with the highest velocity. This problem can be reduced with special multiple nozzles, which, in some cases, leads to energy savings of 30%.

The major difference between the fluidized-bed opposed-jet mill and conventional jet mills is that comminution takes place exclusively in the fluidized bed as a result of the particles impacting against each other, and is thus largely free from wear, because the particles never impact at high speed against the machine wall. The only wear-prone component in the mill is the classifying wheel, which can be protected by selection of a suitable construction material. Monobloc classifying wheels made of aluminum oxide and silicon carbide have proven themselves in operation for even the hardest and most abrasive products.

To prevent high pressure drops and increased wear, it is necessary to operate the classifying wheels at the lowest possible peripheral speeds. For large jet mills with high air flowrates, the highest fineness values can best be achieved with several small classifying wheels. This is due to the fact that at the same peripheral speed, the cut point of classifying wheels shifts into the coarse range with increasing classifying wheel diameter.

The fluidized-bed opposed-jet mill has the following strengths: finenesses down to 3 µm, depending on the product density; low degree of wear, regardless of the product hardness; low product contamination; cool grinding; easy cleaning; quiet operation; and SIP capabilities. These advantages have served to open up a wide range of applications for this mill (Table 6). The largest mills require up to 15,000 m^3/h of compressed air, and the compressors needed to operate the mill are equipped with up to 1,000 kW drive power.

Pros and cons of different mills

Certain product properties can lead to a mill being particularly suitable

TABLE 7: SUITABILITY OF DIFFERENT MILL DESIGNS FOR SPECIFIC APPLICATIONS						
	Mill design					
Material properties	Fine impact mill	Long gap mill	Dual-rotor pin mill	Classifier mill	Spiral jet mill	Fluidized-bed jet mill
Fineness	> 100 µm	> 80 µm	> 32 µm	> 10 µm	> 5 µm	> 3 µm
Top cut	-	o	-	+	+	+
Mohs' hardness < 3	+	+	+	+	+	+
Mohs' hardness > 3	o	o	-	o	-	+
Heat-sensitive materials	o	o	-	o	+	+
Moist materials	o	+ (1)	o	o	-	o
Sticky materials	o	o	+ (2)	-	-	-
Machine sizes						
Rotor diameter, mm	50 – 1,800	200 – 2,800	50 – 1,120	50 – 2,000	30 – 1,000 (3)	40 – 1,800 (3)
Drive power, kW	0.5 – 355	4 – 1,400	2x0.5 – 2x250	0.5 – 500		1,200 (4)
+ ideal; o suitable to a limited degree; - not recommended						

Footnotes: (1) The long gap mill is capable of processing products with a high moisture content — even liquid suspensions — provided that the air is preheated adequately; (2) In combination with wide-chamber design; (3) Diameter of grinding chamber; (4) Drive power of compressor

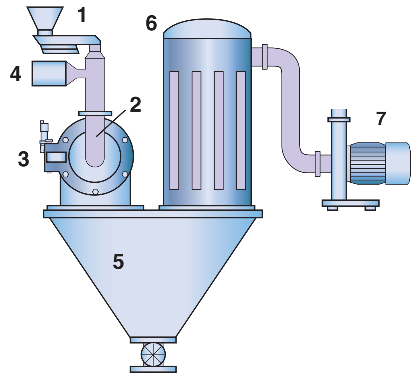

FIGURE 12. A standard impact mill system is composed of: a feeder (1), magnetic separator (2), a mill plus safety switch (3), a silencer (4), a product collection bin (5), an automatic filter (6) and a fan (7)

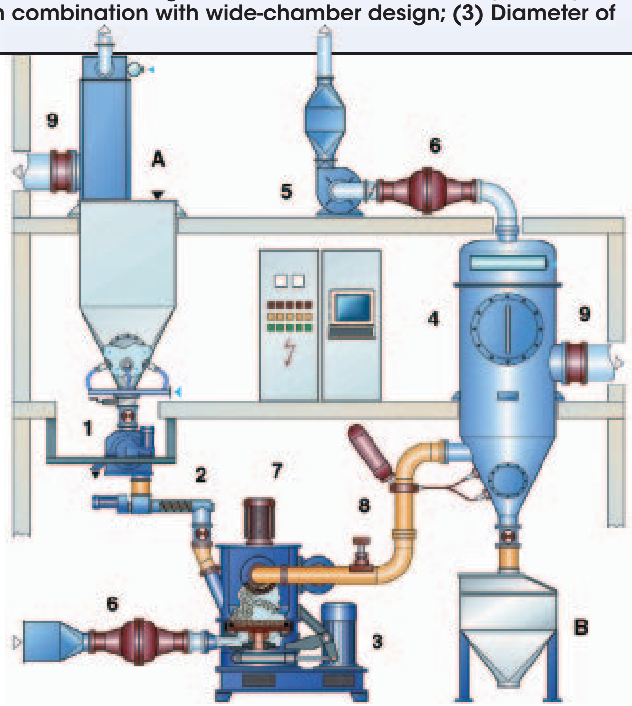

FIGURE 13. Flowchart of a pressure-relieved processing system with classifier mill. [(A) feed; (B) ground material; (1) metal separator; (2) feed metering screw; (3) classifier mill; (4) reverse jet filter; (5) fan; (6) explosion-barrier valve (7) explosion venting; (8) fire extinguishing system; (9) rupture disk]

for a specific application or to it not being suitable at all. Table 7 gives an overview of the suitability of various machine types on the basis of different criteria.

System engineering

An impact mill on its own is not functional; it needs a more-or-less elaborate system for operation. A standard system for the classic impact mill is shown in Figure 12. Feed metering channels or screws (1) ensure a uniform feedrate. A magnet in the feed chute (2) protects the grinding elements from metallic tramp material. The door interlock (3) ensures that the mill cannot be switched on if the door is open and that the door cannot be opened if the rotor is still running. A suction-side silencer (4) reduces the noise at the site of machine installation. A large part of the ground product accumulates directly in the fines collection bin (5), whereas fine dust is collected in the automatic filter (6). A suction fan (7) compensates the filter resistance in order to maintain a slight under-pressure in the system and thus prevent formation of dust. The rotary valve at the base of the fines collection bin discharges the product and serves as an air-lock.

In times with the focus on customized solutions, standard systems play an increasingly insignificant role. Today, solutions are developed for the individual market segments that are more and more specific, whereby the peripheral conditions specified by a product itself must always be taken into account.

Explosion protection

Even though dust explosions are relatively rare, they can cause serious damage to people and machines when they do occur. Besides preventive measures, such as the avoidance of potentially explosive dust concentrations, the avoidance of critical oxy-

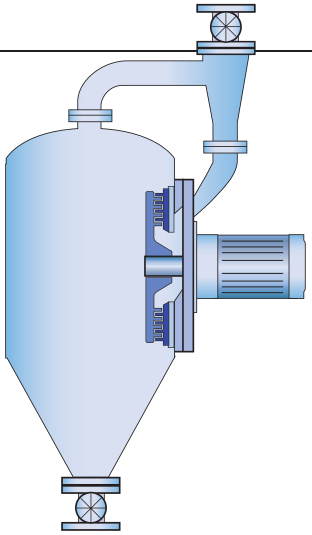

FIGURE 14. Shown here is a compact grinding system with pin mill and two air-locks

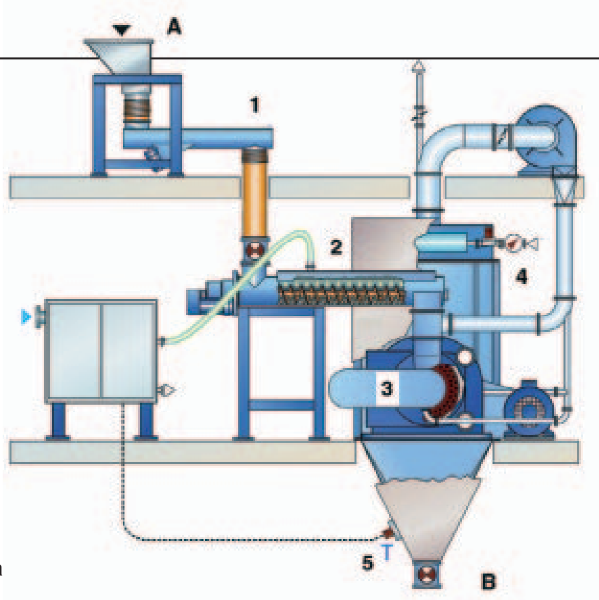

FIGURE 15. Cryogenic grinding system operated with liquid nitrogen [(A) feed; (B) ground material; (1) feed metering channel; (2) screw cooler supplied with liquid nitrogen (LN2); (3) dual-rotor pin mill; (4) automatic filter; (5) temperature sensor]

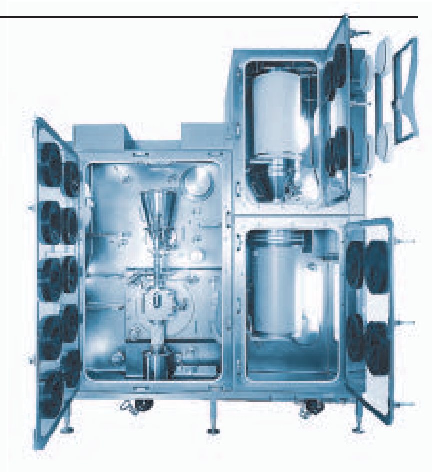

FIGURE 16. This fine impact mill inside an isolator features a mill housing and grinding elements in monobloc design, and polished surfaces (Ra = 0.8 µm)

gen concentrations by inerting and the avoidance of ignition sources, there are a number of design measures that can limit the damage in the event of a dust explosion. In laboratories, for example, inerting is often used — likewise in the pharmaceuticals industry. In the case of large systems, an explosion-pressure, shock-proof design is too expensive, and pressure venting and a reduced explosion pressure is therefore used (Figure 13). Conformance with the explosion protection directives 94/9/EC for manufacturers and 99/92/EC for owners became mandatory in the EU member countries in recent years.

Compact system

In the case of brittle products that have a low grinding energy, there is a high mass flowrate of product through the grinding system. Thus, the system can be cooled by the product and does not need additional cooling by an air flow through the system. A compact system without dust collector can be designed for these applications. This is especially advantageous for potentially dust-explosive products, because the system is so compact that it can easily be built in a 10 barg design to withstand dust explosions (Figure 14). This ensures a safe operation of the system and saves investment costs. An example for the use of such compact systems is milling sugar, which is preferably ground with pin discs (see also Figure 9).

Cryogenic grinding

Some materials that are subject to plastic deformation at ambient temperature can be cooled to make them brittle enough to be subsequently ground by impact. Cryogenic grinding is used for spices to make sure that the flavor and aroma is preserved. At the same time, cryogenic grinding also increases the throughput. Other applications are the fine grinding of plastics and rubber. The supply of nitrogen is controlled as a function of the mill outlet temperature. The temperatures downstream of the mill often range between 0 and –20°C. The nitrogen requirement is considerable and usually ranges between 1 and 3 kg of liquid N_2 per kilogram of product, which naturally raises the costs significantly.

Figure 15 shows a cryogenic grinding system operated with liquid nitrogen. Large sections of the system are insulated to reduce the nitrogen requirement, and the cold air is circulated. Operating in the "through-air" mode is out of the question because freezing water from the air would cause the mill to ice up.

Pharma systems

The demands posed by the pharmaceutical industry are very different, depending on whether active substances or additives are to be processed and in what form the medicine will be administered. In the case of highly active substances, the batches are relatively small, and thus so are the machines and systems used to process these products. Another important point is that the production personnel must be afforded effective protection. This has led to the increasing use of isolators (Figure 16). A machine is much more difficult to operate if housed in an isolator, than under normal conditions. Grinding systems in isolators are unique systems with every detail designed to users' needs.

Final remarks

During the last decades impact grinding has gone through several developments. Dust emissions of systems have been reduced. Products have become finer and finer. Processes have become more stable by using classifiers. Machines have become more reliable in continuous operation. Nowadays customized solutions are available for many applications. Future developments will be: machine diagnosis for planned preventative maintenance, noise reduction, energy efficient grinding processes and use of wear-resistant construction materials to process harder products by impact grinding. ■

Edited by Gerald Ondrey

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VISCOSITY: The Basics

An important concept, sometimes forgotten, is that viscosity is not a single-point measurement

Robert G. McGregor
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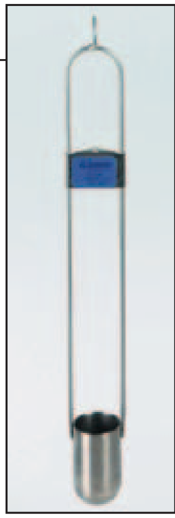

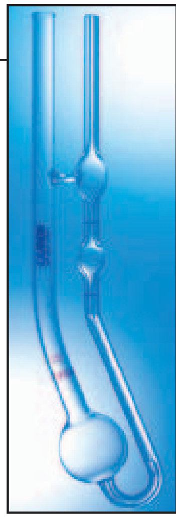

Cannon Instruments of State College PA

FIGURE 1. (top left) Flow cups are used for measuring the viscosity of inks

FIGURE 2. (top right) Capillary viscometers measure kinematic viscosity

FIGURE 3. (left) Rotational viscometers (this one with a disc spindle) measure dynamic viscosity

Most engineers know what viscosity is, but may have trouble explaining it. To be brief, viscosity is resistance to flow. For handlers of all materials that flow, either while being processed or in an end-use, it is important to think about the materials' flow characteristics. The bottom line is to come up with ways to measure viscosity so that you can quantify whether a material will flow the way it needs to.

This article reacquaints the reader with the basic concepts and terminology for viscosity and addresses techniques to quantify it. An important concept, sometimes forgotten, is that a material's viscosity is not a single-point measurement, but often depends on a number of factors.

Take asphalt, for example. The standard test method for pumpability, according to ASTM D4402, is to use a regular viscosity (RV) torque rotational viscometer at 20 rpm or a low viscosity (LV) instrument at 12 rpm. Record the viscosity value, make sure that it falls within prescribed maximum and minimum limits, and then report whether the number passes or fails. However, this straightforward single-point test does not provide the complete picture for asphalt flow behavior. When pumping asphalt, the startup torque required to get the pump going initially suggests that a second viscosity test at a much lower rotational speed makes sense. Experiments have shown that the viscosity values obtained at 0.1 or 0.01 rpm can be several orders of magnitude higher than the one recorded at 20 rpm.

Raw materials in the chemical process industries (CPI) usually have a reported viscosity value on the data sheet that accompanies the product. Data sheets for some polymer solutions, for example, may include a discrete number like 4,500 centipoise (cP), but no further information about how the measurement was made, not even the test temperature at which the polymer was measured. To perform a valid verification check and confirm that the material is within specification requires a duplication of the test method used by the manufacturer. The only alternative in these situations is to find the proper authority at the manufacturer and obtain the relevant test details.

The printing ink industry is one of the best examples to illustrate the need for viscosity measurement. When the ink is too thick, smearing may result during printing; too thin and there can be serious fading of the printed image. There was a time when pressmen could tell by rubbing an ink between their fingers as to how well it would perform "on press". This rubbing action was, in essence, a viscosity test, the objective being to tell how much resistance was felt between thumb and forefinger.

Printers developed a more scientific approach to viscosity measurement by using cups with holes in the bottom to measure how much time it would take to drain the ink (Figure 1). The cups were relatively inexpensive and anyone working the press could easily learn how to make the measurement. This became one of the earliest quality control (QC) tests that checked systematically for viscosity in a quantifiable way. But the cup method could not always discriminate successfully between inks that proved acceptable and those that were marginal or outright poor performers.

The problem turned out to be a matter of understanding "shear rate" and how it can affect the viscosity of the ink. When testing inks, or any material that flows, it is important to think about how the material will be processed or handled when in use. The "shearing action" that the material will undergo is the analysis that we want to focus on. For inks, the use of a rotational viscometer running at different speeds can simulate, in part, what is happening to the ink during transfer to a substrate. This analytical procedure for simulating the shearing action with an instrument is the key

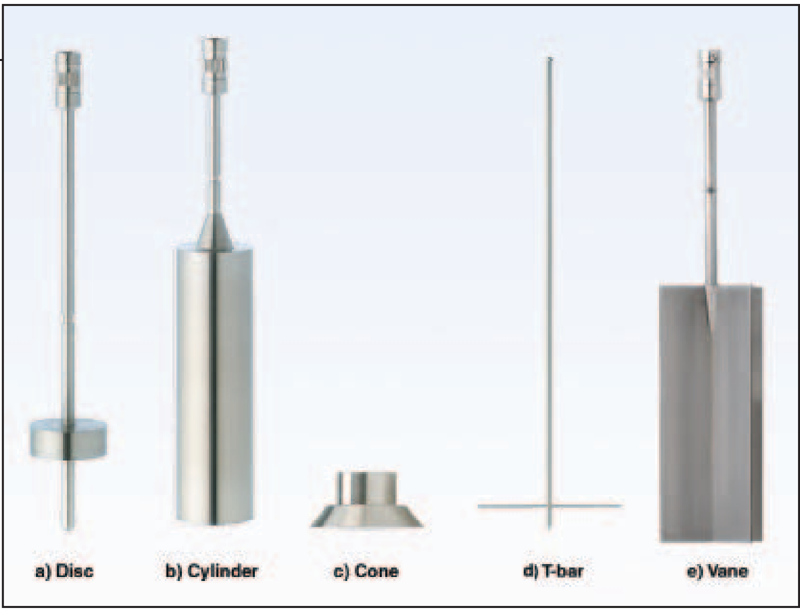

FIGURE 4. Spindle geometries include:
a) Disc; b) Cylinder; c) Cone; d) T-bar; e) Vane

TABLE 1. COMMON MATERIAL VISCOSITIES	
Material	**Viscosity (cP)**
Benzene	0.6–0.7
Sulfuric acid	20–30
Motor Oil SAE 30	150–300
Glycerin	1,000–2,000
Glycerol	1,400–1,600
Asphalt emulsion	>5,000
Grease	>100,000

to predicting flow behavior and leads to the selection of an appropriate viscometer to perform the test work that is required.

Kinematic viscosity

Returning to the cup method, note that this type of test uses the force of gravity to drain the ink out of the cup. The shearing action on the ink takes place at the orifice on the bottom of the cup. As the ink level in the cup goes down, the shear rate at the orifice decreases because the weight of the ink remaining in the cup is less and less. This type of measurement, where gravity is the driving force, is referred to as kinematic viscosity.

The petroleum refining industry is a major user of capillary viscometers (Figure 2), which like the flow cups, also measure kinematic viscosity. A measured sample volume of the fluid flows under the influence of gravity between two etched lines on the tube, and the time of flow is recorded. Taking into account the calibration constant of the capillary tube, these highly precise instruments report data in scientific units of mm^2/s, or centistokes (1 cSt = 1 mm^2/s). The standard test method for many liquid petroleum-derived products is ASTM D445, which also requires strict temperature control when measuring viscosity with the capillary viscometer. This recognizes the effect of temperature on flow behavior and the need to standardize test results by holding temperature constant. Petroleum-derived materials tend to be Newtonian by nature (the viscosity value remains the same, no matter what shearing action takes place), so the high precision of these instruments is very important to achieving accurate viscosity values.

Dynamic viscosity

Rotational viscometers (Figure 3) have become a widely accepted tool for the measurement of viscosity across a number of industries, including certain parts of the petroleum refining world, especially those concerned with low temperature behavior. The spindle, when inserted into the test liquid, rotates at various fixed speeds, thereby shearing the material continuously at defined shear rates. Simultaneously the viscometer measures the amount of torque resistance experienced by the spindle at each speed of rotation. This torque measurement is quantified as a "shear stress", which acts across the surface area of the immersed portion of the spindle. These two key concepts — torque resistance and shearing action — have been combined into an equation that defines dynamic viscosity as the ratio of shear stress to shear rate:

$$\text{Dynamic viscosity}\,(\eta) = \frac{\text{Shear stress}(\tau)}{\text{Shear rate}(\dot{\gamma})} \quad (1)$$

The unit of measurement used to quantify rotational viscosity is the centipoise (cP) in N. America and most of S. America, and the milliPascal-second (mPa-s) in other countries, although there is some degree of overlap in useage. The fortunate news is that the two units are interchangeable because 1 cP = 1 mPa-s.

There is a way to correlate viscosity measurements made with dynamic and kinematic methods for materials that are Newtonian using the following equation:

$$\frac{\text{Dynamic}}{\text{viscosity}} = \frac{\text{Kinematic}}{\text{viscosity}} \times \text{Density} \quad (2)$$

For non-Newtonian fluids, however, the dynamic viscosity must be determined for each shear rate according to Equation (1).

Shear stress: The type of spindle used to shear the material is an important consideration for making viscosity measurements. The standard disc-type spindle is most commonly used throughout the world since its introduction 75 years ago. Since then, a variety of spindle geometries have come into existence including cylindrical, cone, T-bar, vane and many others of various shapes (Figure 4). The most used geometries for "defined shear rate" calculations are coaxial cylinder (cylindrical spindle in a cylindrical chamber) and cone/plate; the equations that define shear stress and shear rate for these configurations are shown in Figures 5 and 6.

The benchmark material for comparing the viscosity of all materials is water. The National Institute of Standards and Technology (NIST; Gaithersburg, Md.) states that the viscosity of water is 1 cP when measured with a capillary viscometer at a temperature of 20°C. Table 1 shows the viscosity of select materials, to give an idea of how they compare to each other.

Shear rate: Shear rate is a reflection of the process characteristics as op-

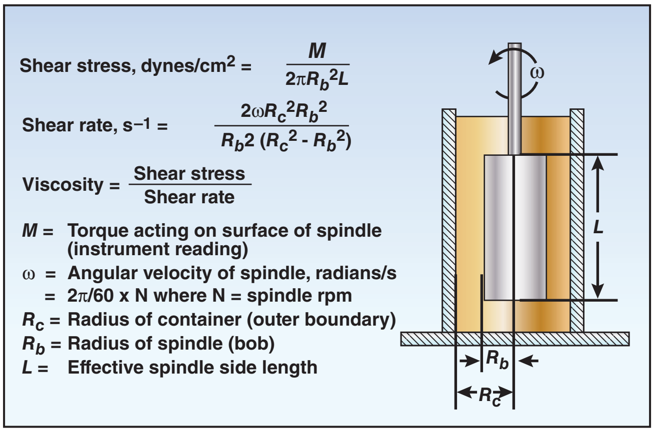

FIGURE 5. Coaxial cylinder geometry calculations

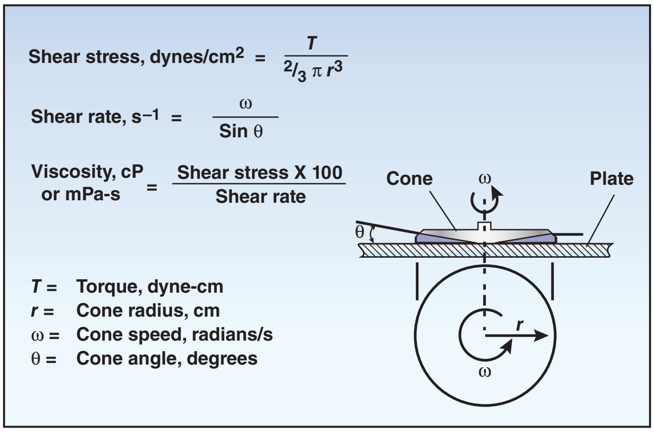

FIGURE 6. Cone-and-plate geometry calculations

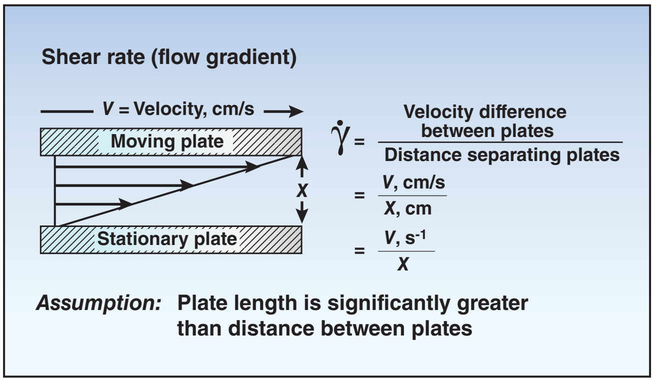

FIGURE 7. This shows graphically how shear rate is quantified

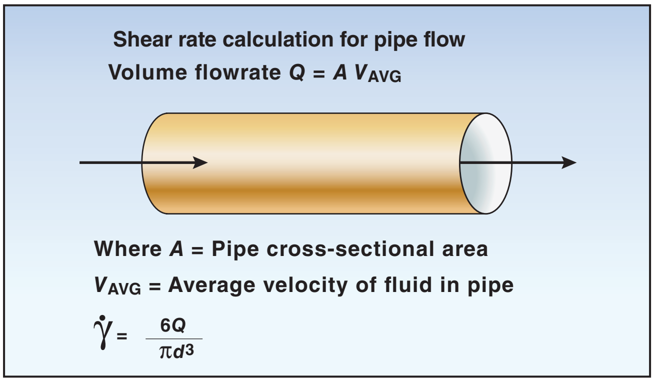

FIGURE 8. Shear rate can be calculated for pipe flow

posed to the process liquid properties themselves and must be quantified separately. Imagine that the fluid you want to test is sandwiched between two plates separated by a known distance. Keep the bottom plate stationary and move the top plate at a defined velocity. Shear rate is the ratio of the moving plate velocity, V, to the distance separating the plates, X.

$$\text{Shear rate} = V/X \qquad (3)$$

The unit of measurement for shear rate is reciprocal second or s^{-1}. This approach to quantifying shear rate assumes that the fluid behaves in a uniform way as shown by the arrows in Figure 7. The layers of fluid molecules slide over each other in a repetitive fashion such that the closer you get to the moving plate, the faster the layer is moving.

Table 2 gives several examples of shearing action and the shear rate associated with each. The thing to recognize is that you can easily compute the relevant shear rates for your own situation. Consider the shearing action in a mixer. The blades are equivalent to the moving plate and the side wall is the stationary plate. The angular velocity of the blades is easily computed based on the rotational speed of the mixer; the distance from the blade to the side wall is a known dimension provided by the manufacturer. The equivalent shear rate is simply the ratio of those two numbers.

A similar calculation can be done for the shear rate of fluid flow in a pipe, as shown in Figure 8, assuming that the velocity profile of the fluid changes linearly from the pipe wall to the center of the pipe where maximum velocity occurs. Although a linear change in velocity profile is not the usual case, it provides a convenient starting point for an initial calculation.

Material behavior

With these fundamental concepts in place, the important conclusion to recognize is that many CPI materials are non-Newtonian and will change in viscosity as the shear rate is adjusted, in other words, viscosity is not a single number for them.

Pseudoplasticity: The most common type of viscosity behavior is pseudoplasticity, where a material's viscosity decreases as the shear rate increases. This behavior can be characterized by a flow curve or rheogram (Figure 9). Many of the materials mentioned in this article, with the exception of water and select petroleum refining products, are pseudoplastic. Water is always 1 cP at 20°C no matter what shear rate is used. Just as materials that do not change in viscosity with shear rate are referred to as Newtonian (in honor of Isaac Newton who first postulated the parametric relationships discussed earlier in this article), those which do change are called non-Newtonian.

Thixotropy: A related issue that affects measured viscosity values is the length of time for the shearing action. If a material is sheared at a constant rate and the viscosity decreases over time, we call that thixotropy. Some materials exhibit thixotropic behavior, but recover completely once the shear-

TABLE 2. TYPICAL SHEAR RATES		
Situation	**Typical shear rate range (s^{-1})**	**Application**
Sedimentation of fine powders in asuspending liquid	10^{-6} to 10^{-4}	Medicines, paints
Leveling due to surface tension	10^{-2} to 10^{-1}	Paints, printing inks
Draining under gravity	10^{-1} to 10^{1}	Painting and coating, toilet bleaches
Extruders	10^{0} to 10^{2}	Polymers
Dip coating	10^{1} to 10^{2}	Paints, confectionery
Mixing and stirring	10^{1} to 10^{3}	Manufacturing liquids
Pipe flow	10^{0} to 10^{3}	Pumping, blood flow
Spraying and brushing	10^{3} to 10^{4}	Spray drying, painting, fuel atomization
Milling pigments in fluid bases	10^{3} to 10^{5}	Paints, printing inks
High-speed coating	10^{5} to 10^{6}	Paper
Lubrication	10^{3} to 10^{7}	Gasoline engines

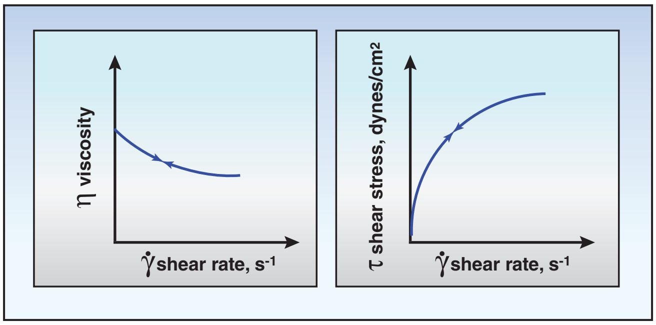

FIGURE 9. Flow curves, or "rheograms", are used to characterize pseudoplastic behavior

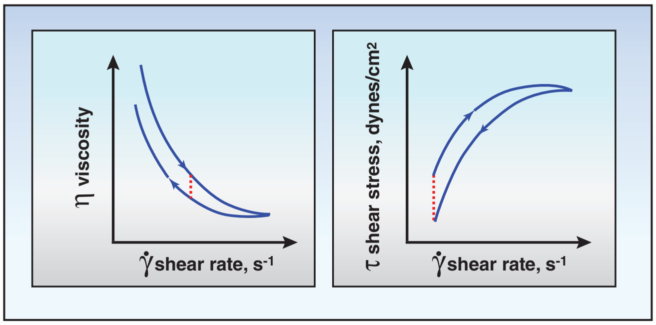

FIGURE 10. This flow curve shows thixotropy in a pseudoplastic material

ing action stops. This is important because the material will not behave as expected by the end user if the loss in viscosity is permanent. For pseudoplastic materials, the way to observe whether thixotropy occurs is to run an up/down test (increase the spindle speed, then decrease the spindle speed) and see if the data for the flow curves are separate, as shown in Figure 10. The spatial area between the curves is an indicator of how significant the thixotropic behavior may be. If the curves lie on top of each other or are relatively close together, there is little to no thixotropy.

Temperature: Temperature is another key parameter that must be considered when measuring viscosity. As temperature increases, most materials exhibit a decrease in viscosity. So it is important to define the temperature at which the viscosity measurement is made to ensure consistency of results. When new materials are evaluated, it is common to perform a temperature profile test. Run a series of up/down shear ramps at discrete temperatures as shown for the ink sample in Figure 11. This allows manufacturers and users alike to take into account variable ambient conditions that may exist in plants around the world, especially if the viscosity measurement is made out on the plant floor and not in a controlled lab environment.

Measuring viscosity

Quality control personnel have a better opportunity to perform effective testing when the above concepts are applied to materials handled or produced in the plant. Most companies use a single-point test to check for viscosity, which means a defined spindle running at a single speed. Hopefully, more thorough testing has already been performed showing complete flow curve behavior so that the choice of a single point is relevant and can distinguish good material from that of lesser quality.

Thix Index: Some CPI companies recognize the need for more than one viscosity measurement in QC and use a long-established method know as the Thix Index. Viscosity measurements are made at two separate speeds, normally an order of magnitude apart, such as 50 rpm and 5 rpm. The viscosity value at 5 rpm is divided by the viscosity value at 50 rpm. For a pseudoplastic material, the ratio of the two viscosities is a number that is greater than 1. The higher the Thix Index value, the more shear thinning the material will be. Some resins companies use this technique regularly and report values as high as 4, which indicates significant pseudoplastic behavior.

Formulations are constantly changing as new additives are introduced to enhance the product behavior or appeal. Textured particles in paints, modified asphalts with various filler materials and specialty polymers are only a few examples that show the need for thorough viscosity testing. They clearly suggest that a single-point test is not enough to give the full picture in QC and that a more detailed analysis will be required. The Thix Index can bridge the gap temporarily, but the ultimate realization is that a

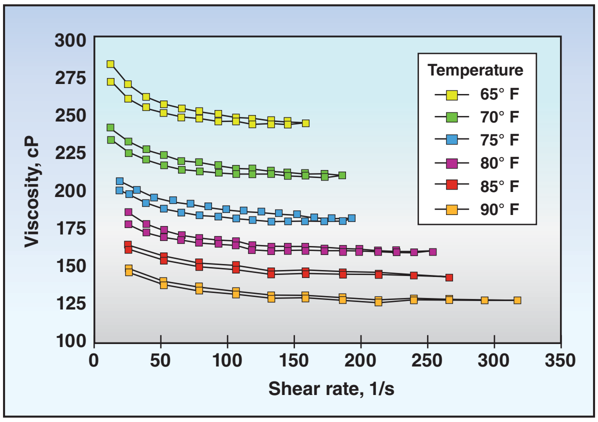

FIGURE 11. A viscosity-temperature profile for an ink sample is shown with data from shear ramp tests

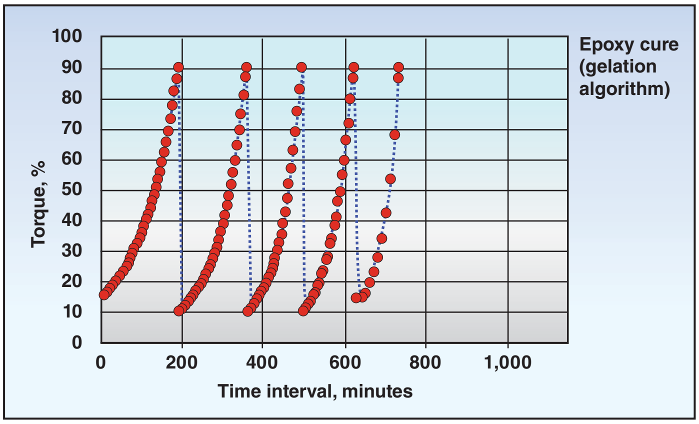

FIGURE 12. These torque data are for a cure test on an epoxy

FIGURE 13. Controlled stress rheometers can accurately measure yield stress

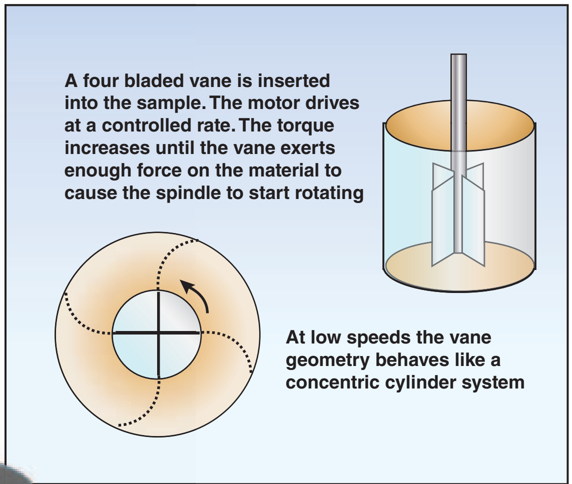

FIGURE 14. Vane spindle geometry may be preferred for yield stress measurements of higher viscosity materials

true viscosity flow curve is needed, and this should become part of the data file that goes with the product record.

Today's instrumentation is fully capable of running multiple point tests and capturing the data without operator involvement. This more-involved capability does not take any more labor to accomplish. In fact, it may require less since the results don't have to be manually written down, but instead are captured automatically.

Curing algorithm: One new test method that has become readily available to the CPI through the inexpensive automation of instrumentation is the "curing algorithm," which allows prediction of an endpoint in a benchtop test. This applies to adhesives, asphalts and select polymer manufacturers who need to know how a reaction is progressing as evidenced by the buildup of viscosity in the material. The viscometer measures viscosity continuously as it builds over time, while rotating the spindle at a defined speed, say 100 rpm at the outset. When the torque reaches a defined maximum, say 95% for example, the spindle speed automatically drops by an order of magnitude to 10 rpm, and the measurement continues without interruption. Again, when the torque reaches 95% as the material continues to build viscosity, the speed drops to 1 rpm, and so forth. The standard instrument shown in Figure 3 can go down to 0.01 rpm. Figure 12 shows the type of viscosity data that results. In addition, the time to cure is also recorded. The advantage of today's instruments with built-in microprocessors is that the test runs can be unattended, and the data are captured automatically by a personal computer.

Yield stress: Viscosity may be the primary variable of interest, but there is a related parameter called yield stress that is critical to measure for some materials. Yield stress is the amount of force that is required to get a material to begin flowing. Returning to the asphalt example earlier in this article, the idea can be applied to any pumping situation. In order to move the material from one point to another, the startup torque required for the pump must be calculated so that the pump is sized correctly. Therefore, the yield stress in the material must

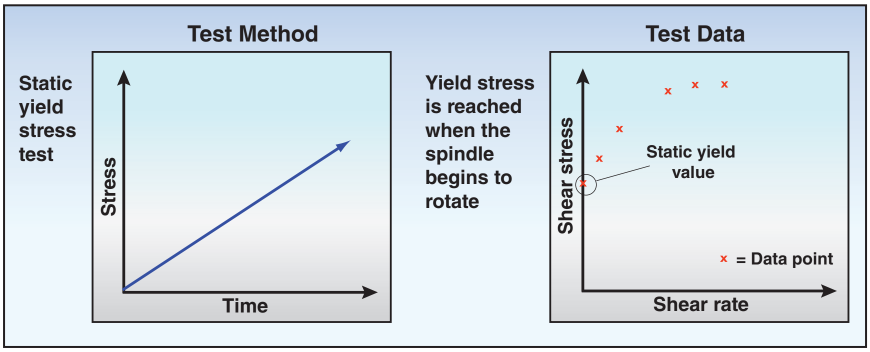

FIGURE 15. Yield-stress-test data are obtained from a controlled stress rheometer

be measured and used as the basis for choosing a pump with sufficient startup torque.

The controlled stress rheometer is the tool of choice for measuring yield stress (Figure 13). The choice of spindle geometry must again be considered. If the quantity of available material is limited, say 2 mL or less (which is often the case with specialty polymer formulations), the cone/plate or plate/plate system is the best choice. Alternatively, coaxial cylinder geometry may also be considered if the available sample size is between 2 and 20 mL. When sample size is not an issue, then vane spindle geometry may be preferred. One advantage of vanes is that the material trapped between the vanes is shearing against the material outside the circumference of the spindle (Figure 14). Other spindle geometries sometimes have the problem referred to as "slip", where the material in contact with the spindle surface does not move at the same velocity as the rotating spindle. The vane spindle overcomes this potential problem.

The test method for controlled stress is to run a shear ramp. Increasing torque is applied to the spindle until rotation begins, which is essentially the onset of yield stress. The method is depicted in Figure 15. The test is usually short in duration and provides a numerical value that can be used by process engineers for determining the yield stress of the material. This in turn can be used in sizing calculations for the pump and the startup torque performance as well as steady operation at full flow conditions.

Controlled stress rheometers are expensive instruments and sometimes don't fit into the budget when this type of information is first needed. An alternative approach is to use the flow curve data (shear stress versus shear rate) from a standard benchtop viscometer and extrapolate the data to zero shear rate conditions (Figure 16). This provides a value for what the yield stress might be, but is most likely not as accurate as the controlled rheometer method. If the test is repeated on multiple samples, and similar values are achieved, the result can be the basis for at least a ballpark value for yield stress. ■

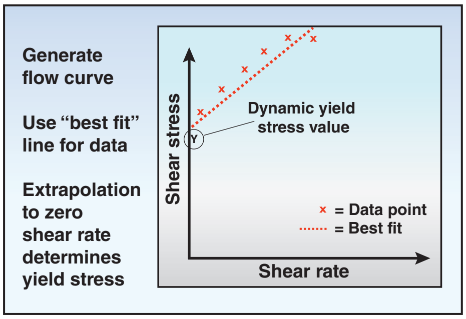

FIGURE 16. When a controlled stress rheometer is not available, yield stress can be approximated using flow-curve data

Edited by Dorothy Lozowski

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REACH: Looking Beyond Pre-registration

The next steps to ensuring compliance are significantly more complex

Nancy Russotto
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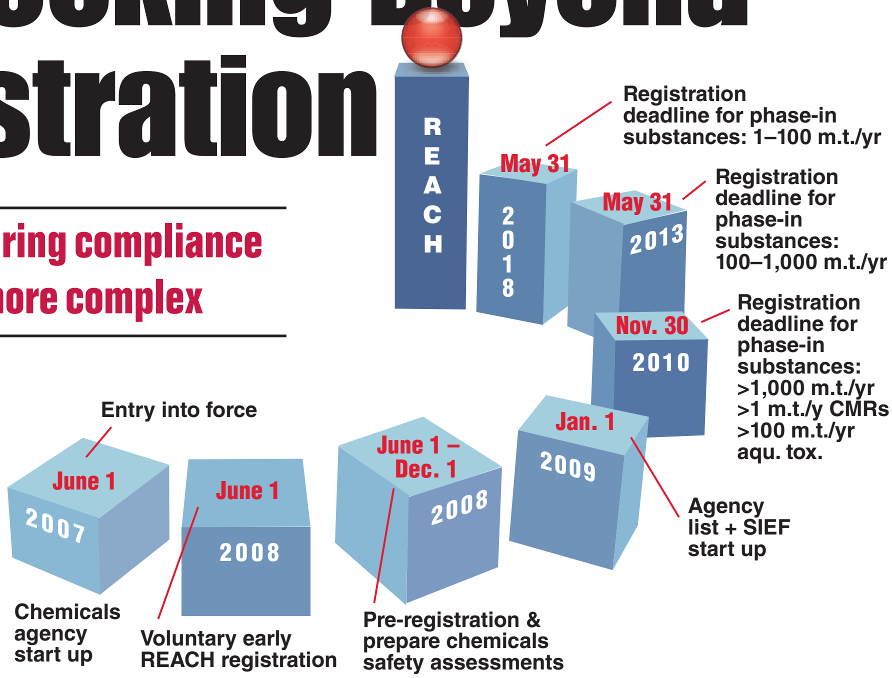

FIGURE 1. The next major deadline in the REACH timeline is November 30, 2010, at which point substances meeting the following criteria must be registered: 1) classified as carcinogenic, mutagenic or toxic to reproduction (CMR) in quantities ≥ 1 m.t./yr; 2) classified as very toxic to aquatic organisms and that may cause longterm adverse effects in the aquatic environment (represented as aqu. tox. above), in quantities ≥ 100 m.t./yr; 3) phase-in substances manufactured or imported in quantities ≥ 1,000 m.t./yr per manufacturer or per importer

Failure to register under REACH closes EU markets for thousands of chemical substances manufactured or marketed in the European Union, whether on their own, in preparations (formulations) or released from articles (finished products). A key policy objective of registration under REACH (EC Regulation 1907/2006 on Registration, Evaluation, Authorization and Restriction of Chemicals) — to shift the burden of proving the safety of chemicals to the private sector — is officially underway.

EU Member States are in the process of issuing national rules on sanctions (from fines and market withdrawal to criminal penalties) for non-compliance with REACH. Equally, customers are demanding proof of REACH compliance. Companies that did not preregister (see box, p. 41) are legally bound to suspend sales and manufacturing in the EU and immediately prepare for submission of a registration dossier.

With all attention to date focused on pre-registration, few companies planned beyond that stage in the process. It is becoming increasingly apparent that the next steps to ensure compliance under REACH are significantly more complex and require not only technical skills but also substantial legal advice, supply chain management and adjustments in logistics. Compliance can also engender financial consequences that need to be carefully managed.

This article sets out the key steps that every company must understand, suggests pitfalls to be avoided and raises awareness of some of the related initiatives that companies might need or wish to consider. For an explanation of what falls under REACH, see the box, p. 42. Meanwhile, for more about the specific requirements of REACH, see *CE*, March 2008, Cover Story Part 1, Are You Ready For REACH? and Part 2, REACH: A Timely Overview.

Registration deadlines

Dates for registration depend on the type of substance, volume and hazard classification (Figure 1). Every company must ensure that its REACH-relevant products are placed in the appropriate order of priority for fulfilling the requirements. Note that the first registration deadline for properly pre-registered substances is November 30, 2010, at which point substances meeting the following criteria must be registered:

- Classified as carcinogenic, mutagenic or toxic to reproduction in quantities ≥ 1 metric tons (m.t.) per year
- Classified as very toxic to aquatic organisms and that may cause longterm adverse effects in the aquatic environment, in quantities ≥ 100 m.t./yr
- Phase-in substances manufactured or imported in quantities ≥ 1,000 m.t./yr per manufacturer or per importer

Supply chain communications

REACH requires supply chain communications, particularly for the purposes of registration, among substance manufacturers, formulators, article producers, importers, distributors and downstream users both within and outside of the EU.

REACH requires suppliers of articles containing substances of very high concern (SVHCs) to forward information on these substances, if contained above a concentration of 0.1 wt.%, to the industrial or professional user (or distributor) being supplied with the article. If a consumer requests such information, REACH

ABOUT PRE-REGISTRATION

Pre-registration, which closed on December 1, 2008, was the essential first step in order for potential registrants of certain "phase-in" substances (mainly substances listed in the European Inventory of Existing Commercial Chemical Substances; EINECS) to benefit from extended registration deadlines. These deadlines varied according to the hazard classification of each chemical and volumes manufactured in, or imported into, the EU. The 2.5 million pre-registrations completed prior to the deadline exceeded the anticipated number by 2.3 million and illustrated the effort by companies worldwide to ensure continued market access in the EU. While it is estimated that this number is inflated by duplicate and superfluous pre-registrations, it is clear that between 100,000 and 150,000 substances were legitimately pre-registered.

Pre-registrants benefit from continued lawful market access for the pre-registered substance until the relevant registration deadline. Companies that missed the December deadline must fulfil their registration requirements now in order to continue to market legally in the EU.

Late pre-registration

Late pre-registration for new parties is available, only under limited conditions. It is possible for companies that fall under a narrow set of criteria to pre-register after the deadline. The exception applies to the following:

- New EU manufacturers and new EU importers
- Representatives of new non-EU manufacturers and new non-EU formulators
- New EU producers and new EU importers of articles (with substances intended to be released under normal or reasonably foreseeable conditions of use). ❑

requires that the supplier provide the same information within 45 days of receipt of the request.

In today's markets where sensitivities to environmental and health impacts run high and campaigns target products that allegedly expose consumers to unwanted risks, companies must deal not only with formal regulatory requirements but must also protect their markets by adequate and appropriate communications throughout the supply chain.

Cooperating with competition

Pre-SIEF and SIEF. For the first time under REACH, all competitors having pre-registered a phase-in substance need to organize themselves to provide or generate data required for registration. Because members of a SIEF (Substance Information Exchange Forum) need to agree on the group's "Lead Registrant", companies need to determine the profile they wish to adopt in each substance-related SIEF. For example, a company whose substance is of great commercial value might wish to be involved in the management of the SIEF, even to become its Lead Registrant. For substances of lesser business value, a more passive role might be appropriate. It will be important to assess the time and financial investment relative to the profile adopted.

In either case, it is important to note that the members of a given SIEF are being urged to to submit lead registration dossiers by June 2010 (six months early) to be safe. Such timing would allow a technical completeness check and make sure that the registration is officially completed in time for other members of the SIEF to refer to the lead registration dossier.

The immediate priority during the current pre-SIEF period (between the end of the pre-registration window on December 1, 2008 and the formation of the SIEF) is for all the pre-registrants for each substance to agree on substance sameness. This means agreeing that the substances have the same chemical identity, in other words, that the chemical composition and hazard profile of a substance produced from different sources are sufficiently similar to be part of the same joint registration.

Because the pre-SIEF and SIEF activities bring together competitors, members need to ensure that the management of meetings protects individual companies from any potential infringement of competition (anti-trust) rules. On a company-specific level, professional guidance will be required to handle areas such as data evaluation and cost-sharing of existing data or data to be generated by the group. Many companies are opting for entering, or have already entered, into consortium agreements with their competitors in order to formalize the terms on which they cooperate in order to fulfil REACH obligations.

Cooperation with competitors in a SIEF is mandatory for phase-in substance pre-registrants. In contrast, participation in a consortium is voluntary and is motivated by the mutual benefit of its members. The duration of a consortium and its relevant SIEF are not necessarily the same. The duration of a consortium may extend beyond the life of the SIEF, post June 2018, or vice versa. There may also be differences in membership. Participants in the SIEF will include the following: 1) registering manufacturers, importers or so-called Only Representatives; 2) parties whose substances are regarded as being registered because they are regulated by the Plant Protection Product Directive or Biocidal Product Directive; and 3) data holders that are not required to preregister under the regulation but that wish to join the SIEF in order to sell relevant data (for example, laboratories, trade associations, and certain downstream users). In contrast, consortia will not necessarily involve all SIEF members and may include participants who are not part of the SIEF, like third parties that are not data holders (for example trade associations or service providers, such as law firms) or those producing or importing a substance in the EU for the first time after closure of the pre-registration window.

Many of these same management considerations apply to consortia. Companies need to analyze the business value of creating or joining a consortium. They should evaluate the financial demands inherent in joining such groups and, in some cases, participate actively in the determination of the fees. Another critical step for each company is to ensure protection of its own intellectual property as data sharing mechanisms are implemented.

Legal agreements will need to be drafted concerning, among other things, consortia, confidentiality, data licensing, cost-sharing, lead-registrant obligations and work with contract laboratories.

Competition, or anti-trust, compliance is an area that companies need to examine both to ensure the proper management of pre-SIEF, SIEF and consortia meetings and their documentation and to prepare individuals in the company for appropriate behavior at such collective meetings and in correspondence with competitors. Training should be organized and, where absent, competition compliance schemes developed and documented.

Data management requires a secure, user-friendly information technology (IT) system for management of a company's complete compliance activities. With varying deadlines, different levels of participation in collective groups, data provision or generation activities, financial and logistical considerations, a company will be quickly overwhelmed if there is not a management system in place for tracking involvement and managing deadlines.

Business strategies

Every company will need to develop its own strategy for sourcing data to fill crucial data gaps, including the following: literature search and review; data valuation; study protocol recommendations; provision of cost estimates; sourcing contract research organizations and studies (for instance, acquisition from other SIEF members, further testing and so on).

Each company will need to review the adequacy of registration activities and determine further measures needed. The preparation of Chemical Safety Assessments (CSAs) and Chemical Safety Reports (CSRs) needs to be organized or adapted to the REACH requirements. Classification and labelling considerations need to be understood and the appropriate value chain communications implemented. In some instances, there may be a need for product-specific advocacy with regulators at either the EU or national level.

A company with multi-national or global activities needs to be aware of the increasing appeal of REACH to regulators in other parts of the world, from the U.S. State of California to the People's Republic of China, and the possibly of equivalent legislation being adopted outside the EU. REACH is seen by many as a desirable evolution in chemicals legislation; and because it is having a worldwide impact, it will be an attractive package for regulators to consider. Companies may wish to make their views known on such an evolution in their own region with well-prepared and documented information.

Post-registration brings its own requirements, for example, the need to respond effectively to questions raised by the European Chemicals Agency or national authorities.

Authorization dossiers require special care in their submissions and will need to include relevant socio-economic and alternatives analyses.

Product defense. REACH has already sparked significant pressures from suppliers and customers to defend substances against deselection by the market and restrictions to use. Constructive interaction with policy makers, not only in Europe but also in the relevant world regions, will be a necessary part of protecting markets for substances and managing the development of and transition to alternative products. Companies need to integrate such considerations into their REACH compliance strategies.

Value chain relationships. As mentioned under "supply chain communications" above, the relationships between each level in a substance's so-called value chain will become increasingly important as debate increases around the safety and role of specific substances. It is of critical importance that these relationships be well managed. Issues need to be anticipated, and creative solutions to real and perceived difficulties should be provided. ■

Edited by Rebekkah Marshall

WHAT FALLS UNDER REACH?

Each EU manufacturer or importer of certain substances in volumes of 1 metric ton (m.t.) or higher — whether alone, in preparations (formulations) or contained in finished products (articles) and intended to be released under normal or reasonably foreseeable conditions of use — must register that substance with the European Chemicals Agency (ECHA).

In addition, certain specific information must be provided to ECHA for each substance in an article that meets certain criteria and is defined as a "substance of very high concern" (SVHC) in the "candidate list" of substances subject to authorization.

Eventually, legally marketing of candidate-list substances will only be allowed if the substances are formally authorized by ECHA. Such authorization will only be granted if it can be shown that the socio-economic benefits of the substance's use outweigh its public health and environmental risks and that there are no less-dangerous, suitable alternatives.

Finally, even substances in smaller quantities than the 1-m.t. threshold may be subject to obligations under REACH, including those obligations concerning restrictions, authorization and Safety Data Sheets (SDS).

REACH affects the following operators in the chemical substances supply chain: ❑

OPERATORS AFFECTED BY REACH

Established in the EU	Established outside of the EU
Manufacturers	Manufacturers
Importers	Formulators (for instance, dye producers)
Exporters out of the EU	Exporters into the EU
Downstream users	Producers of articles
Distributors	
Producers of articles	

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Keeping Cooling Water Clean

Proper monitoring and control of water chemistry is essential

Brad Buecker
AEC PowerFlow

Cooling water systems that rely on cooling towers are a critical component at chemical process industries (CPI) facilities. However, during operation, these open recirculating systems concentrate the contaminants in the makeup water, and as a result, scale formation and biological fouling can occur. To manage this problem, all cooling water systems require proper chemistry control and monitoring. Unless prevented, corrosion and the build up of scale and microbial fouling can impact cooling efficiency and in extreme cases even lead to unit shutdown. This article examines some of the fundamental concepts and treatment options that should be considered to keep open, recirculating cooling systems clean.

When handling any water-treatment chemicals (both oxidizing biocides and non-oxidizing treatment regimens), safety is an absolutely critical issue. Users should follow all recommended safe-handling procedures and vendor recommendations. Adherence to proper safe-handling guidelines, and the use of proper personal protective equipment is essential, as many of the aggressive treatment chemicals discussed below will attack human cells, just as they attack the microbes they are designed to kill.

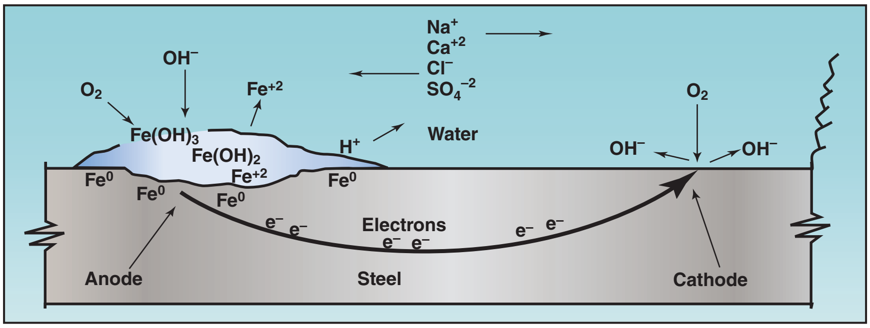

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FIGURE 1. In a basic oxygen corrosion cell, iron dissolution and metal loss occur at the anode, and oxygen reduction takes place at the cathode

Chemical treatment options

The discussion that follows focuses on cooling tower systems that take makeup from fresh water sources, such as lakes, rivers, groundwater, or municipal water supplies. The vast majority of the 300,000 or more cooling towers operating in the U.S. today are supplied from these sources. Table 1 provides a representative analysis of the water quality from a lake in the Midwest that supplies a large power station.

Although fresh water has relatively low levels of the minerals calcium and magnesium, scale may form during summer months, even in once-through condensers and auxiliary heat exchangers, because of the higher seasonal water temperatures. Given the huge number of heat exchangers and condensers at refineries, chemical plants, power plants and other chemical process facilities, any exchangers that rely directly or indirectly on a raw water supply for cooling may be subject to fouling.

If the water used in an open recirculating system has not been properly treated to remove unwanted constituents, the dissolved species in the water will become progressively concentrated. As solubility limits become exceeded for calcium carbonate, calcium sulfate, magnesium silicate, and other compounds, scale will form. The buildup of calcium phosphate [$Ca_3(PO_4)_2$] is also of concern in systems where phosphate or phosphonates (organic phosphate compounds) are used for scale and corrosion prevention. In fact, at one time calcium phosphate challenged calcium carbonate as the most prevalent scale-forming substance in such systems, because calcium phosphate deposits can be very heavy and insulating.

Many modern chemistry programs operate under alkaline conditions, to minimize corrosion. Nonetheless, corrosion protection is still important, so we will examine some corrosion fundamentals as a precursor to the later discussion of treatment options for scale control.

TABLE 1. REPRESENTATIVE LAKE WATER ANALYSIS

Ion	Concentration, mg/L
Calcium	60
Magnesium	12
Sodium	32
Potassium	7
Chloride	32
Sulfate	77
Bicarbonate	163
Nitrate	0.5
Silica	2
Iron	0.1
Manganese	0.1

A typical corrosion cell is shown in Figure 1. As is true for all electrical flow, a circuit must be established for the reaction to proceed. In this example, iron atoms give up two electrons at the anode and the atoms dissolve into the solution.

$$2Fe \rightarrow 2Fe^{+2} + 4e^- \quad (1)$$

The electrons flow through the metal substrate to the cathode, where they reduce a common species in the water. In typical neutral to alkaline cooling waters, the primary reactant is oxygen.

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \quad (2)$$

The ions formed at the anode and cathode migrate toward each other, completing the circuit. The overall corrosion reaction is:

$$2Fe + O_2 + 2H_2O \rightarrow 2Fe(OH)_2 \quad (3)$$

Ferrous hydroxide [$Fe(OH)_2$] will further oxidize to ferric hydroxide [$Fe(OH)_3$] and eventually turn to rust ($Fe_2O_3 \bullet xH_2O$).

Water-treatment programs that slow down either the anodic or cathodic reactions, or both, will reduce the corrosion rate. (Note: Anodic inhibitors, if not carefully monitored for residual chemical levels, can lead to the formation of a few anodic sites in a large cathodic field. Quick and damaging pitting is then likely to occur.)

Just a few decades ago, a very common treatment program for cooling towers was to use sulfuric acid injection (to remove bicarbonate ions and minimize calcium carbonate scaling potential) combined with chromate (CrO_4^{-2}) feed. These chromate-based, pH-adjustment programs were very effective and generally made life easy for the cooling water chemist. Chromate establishes a protective surface coating that resembles stainless steel.

However, the toxicity of chromate has led to severe restrictions on the use of this chemical, so modern treatment programs have generally evolved into alternative, non-chromate methods that operate at a mildly alkaline pH. Operation at alkaline pH itself helps to reduce corrosion, but higher pH increases the potential for scale formation, particularly from calcium carbonate and calcium phosphate.

Consider the following example of untreated water in the cooling system. As the water is cycled, the first compound that tends to come out of solution is calcium carbonate.

$$Ca^{+2} + 2HCO_3^- + heat \rightarrow CaCO_3\downarrow + CO_2 + H_2O \quad (4)$$

A straightforward and often-used method to reduce the potential for calcium carbonate scaling is to treat the makeup with sulfuric acid (H_2SO_4), where the hydrogen ions (H^+) from the acid convert the bicarbonate to carbon dioxide (CO_2). The gas exits from the cooling tower.

$$H^+ + HCO_3^- \rightarrow CO_2\uparrow + H_2O \quad (5)$$

FIGURE 2. Two commonly used phosphonates (shown here) are 1-hydroxyethylidene-1,1-diphosphonic acid (HEDP) and 2-phosphono-butane-1,2,4-tricarboxylic acid (PBTC). Phosphonates help to inhibit the formation of calcium-based scale in cooling water systems

However, acid feed alone may not eliminate scaling. Upsets of acid feed systems can lead to corrosion or scaling, and sulfuric acid introduces sulfate ions (SO_4^{-2}) to the water, which may in turn lead to calcium sulfate deposition. Accordingly, supplemental chemicals are normally employed in cooling tower programs to further minimize scale formation.

One common treatment method was the use of phosphates, either ortho-phosphate (PO_4^{-2}) or phosphate complexes, that would revert to orthophosphate, to precipitate calcium as calcium phosphate [$Ca_3(PO_4)_2$]. These programs also provided corrosion protection because phosphate will react with ferrous ions (Fe^{+2}) produced at anodic sites to form a protective barrier, while calcium phosphate precipitates in the local alkaline environment at cathodic sites.

However, even small upsets in phosphate programs can cause severe calcium phosphate fouling. Accordingly, treatment methods have evolved to more-forgiving methodologies, where in many cases the backbone of these programs is still an organic phosphate (a phosphonate) that is used in conjunction with a supplemental polymer to sequester and modify the crystal structure of scale-forming ions and compounds (Figure 2). In essence, phosphonates attach to deposits as they are forming and disrupt crystal growth and lattice strength.

Careful monitoring and control of phosphonate programs is still required, as overfeed of phosphonates can lead to calcium-phosphonate deposition. Conversely, phosphonates exhibit varying degrees of susceptibility to degradation from thermal and chemical stresses, where oxidizing biocides in particular may cause component breakdown. Degradation will of course reduce the effectiveness of the phosphonates, and will also increase the orthophosphate concentration and the potential for the deposition of calcium phosphate.

A common phosphonate treatment program might include one or perhaps two of the phosphonate compounds, used in relatively low-mg/L dosages for primary scale control. For instance, dosages as low as 5 mg/L of orthophosphate can be used for additional scale control and corrosion protection, and zinc can be used in dosages as low as 0.5 to 2.5 mg/L (zinc dosage is temperature-dependent). Zinc reacts with the hydroxyl ions generated at cathodes to form a precipitate [$Zn(OH)_2$], which provides additional cathodic protection. Also typically included in this formulation is a small dose of an organic polymer for control of calcium phosphate deposition.

Original polymers developed for these applications contain carboxylic acid functional groups (COOH), where the negatively charged oxygen atoms bind with calcium to modify crystal growth. More advanced compounds, such as terpolymers, have a structure that includes carboxylic, amide ($R-CO-NH_2$), and sulfonic acid (SO_3H) groups for improved reactivity and resistance to degradation. However, zinc, like many other metals, is falling under tighter regulatory guidelines, so zinc may no longer be acceptable as an additive in many locations.

One program that has gained much popularity in recent years is based upon the use of a phosphino succinic oligomer (PSO) with a supplemental, but slight, orthophosphate dosage and a polymer to inhibit calcium phosphate deposition. The PSO molecules contain both phosphate-oxygen and carboxylic functional groups.

One complicating factor of the above-mentioned programs is that at

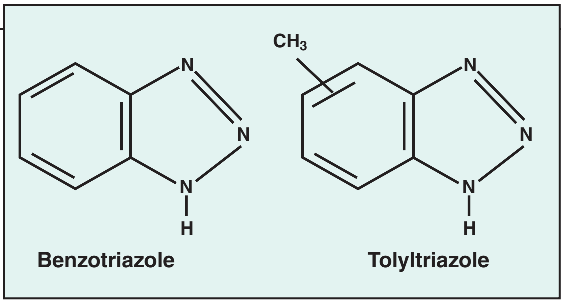

FIGURE 3. **Shown here are the basic structures of benzotriazole and tolyltriazole. The plate-like structure of the organic rings help these compounds to form a protective surface layer on metal components**

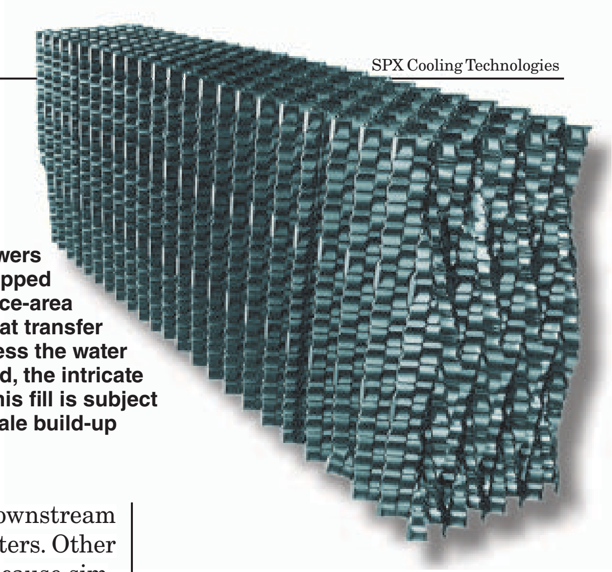

FIGURE 4. **Cooling water towers are typically equipped with a high-surface-area fill to promote heat transfer and cooling. Unless the water is properly treated, the intricate surface area of this fill is subject to fouling and scale build-up during operation**

some locations, phosphate-containing chemicals for cooling-water treatment are banned, as they provide a potent nutrient for vegetative growth. No doubt many readers are aware of algae blooms, which can seriously disrupt surface water chemistry and kill aquatic life. For cooling tower applications, treatment programs are available or are being further developed in which scale control is maintained with polymers that contain no phosphorous.

In systems that have copper alloy heat exchanger tubes (often referred to as yellow metal components), the treatment program should include an azole. Tolyltriazole and benzotriazole have been the most commonly used, but others are evolving (Figure 3).

A low dosage of triazoles (on the order of 2–3 mg/L) is typically required for corrosion control. The most widely accepted theory regarding the protection mechanism is that the nitrogen in the triazoles bonds with copper to form a plate-like molecular layer at the metal surface. Once this occurs, the azoles prevent the penetration of corrosive species.

Tolyltriazole, while being the least expensive of this family of compounds, is also the most subject to decomposition by oxidizing biocides. Benzotriazole is a common replacement, but newer halogen-stable azoles are also gaining in popularity. These compounds include an extra organic side chain attached to the fused benzene ring. They are more expensive than the basic azoles, but greater stability and longer residence times can make them cost-effective in the long run.

Cooling towers are very efficient air scrubbers, as the circulating water inside the tower will capture dust and many other airborne contaminants. From personal experience I know that cottonwood seeds can be particularly nasty, as they will foul downstream equipment, most notably filters. Other airborne contaminants can cause similar problems (Figure 4).

Suspended solids will naturally become concentrated in the system and settle in and on heat exchanger tubes, reducing their heat transfer efficiency. One of the most common methods to remove these foulants is via continuous, side-stream filtration, where a slipstream is routed through a mechanical filter. The flowrate through the filter can be as low as 1 to 5 vol.% of the total cooling water flow, as even this fractional rate will help to reduce the solids buildup in the system.

Microbiological control

The management of microbiological fouling presents another challenge for cooling-water systems. By their very nature, water-based cooling systems provide an ideal environment — warm and wet — for microbes to flourish. Unless properly controlled through the use of biocides, bacteria will grow in condensers and cooling-tower fill, fungi will flourish on and in cooling-tower wood, and algae will grow on wetted tower components that are exposed to sunlight. Thus, biocide use is absolutely essential to maintain system performance and integrity.

In general, three different types of bacteria must be controlled:

- *Aerobic bacteria:* Utilize oxygen in the metabolic process
- *Anaerobic bacteria*: Live in oxygen-free environments and rely on other sources (such as sulfates, nitrates, or other donors) for their energy supply
- *Facultative bacteria*: Can live in either aerobic or anaerobic environments

A big problem with bacterial growth is that once the microbes settle on a surface, the organisms secrete a polysaccharide layer for self-protection. This film will accumulate silt from the water, growing even thicker and further reducing heat transfer at those surfaces. Even though the bacteria at the surface may be aerobic, the secretion layer allows anaerobic bacteria to flourish underneath. These microbes in turn can generate acids and other harmful compounds that directly attack the metal.

Microbial deposits also establish concentration cells, where the lack of oxygen underneath the deposit causes the locations to become anodic to other areas of exposed metal. Pitting often results.

Meanwhile, fungi will attack cooling tower wood in an irreversible manner — in some cases, leading eventually to structural failure. Algae will also foul cooling tower spray decks, potentially leading to reduced performance and unsafe working conditions.

At the heart of any microbiological treatment program is the use of an oxidizing biocide to kill organisms before they can settle on condenser tube walls, cooling tower fill and other locations.

Chlorine has been the workhorse biocide for many years. When gaseous chlorine is added to water, the following reaction occurs:

$$Cl_2 + H_2O \leftrightarrow HOCl + HCl \qquad (6)$$

In this case, HOCl (hypochlorous acid) is the killing agent. The functionality and killing power of this compound are greatly affected by pH due to the equilibrium nature of HOCl in water.

$$HOCl \leftrightarrow H^+ + OCl^- \qquad (7)$$

OCl^- (the hypochlorite ion) is a much weaker biocide than HOCl, probably due to the fact that the charge on the OCl^- ion does not allow it to penetrate bacterial cell walls. The killing efficiency of chlorine dramatically declines as pH goes above 7.5. Thus, for the common alkaline scale and corrosion treatment programs — which intentionally maintain pH above 7 — chlorine chemistry may not be efficient. Chlorine demand is further affected by ammonia or amines in the water, which react irreversibly to form the much less-potent chloramines, the primary example being monochloroamine (NH_2Cl).

Due to safety concerns, liquid bleach ($NaOCl$) feed has replaced gaseous chlorine at many facilities. The major difficulty with using bleach is that the typical industrial-grade bleach contains small amounts of sodium hydroxide. Thus, when it is injected into the cooling-water stream it raises the pH, if by only a small amount.

A popular alternative is bromine chemistry, where a chlorine oxidizer and a bromide salt, typically sodium bromide ($NaBr$), are blended in a makeup water stream and injected into the cooling water. The chemistry produces hypobromous acid ($HOBr$), which has similar killing powers to $HOCl$, but functions more effectively at alkaline pH.

Another factor in favor of bromine is that it does not react irreversibly with ammonia or amines. However, the primary disadvantages of bromine use are that an extra chemical is needed, and feed systems are a bit more complex than for bleach alone.

Chlorine dioxide (ClO_2) has found some application as an oxidant for two primary reasons. Its killing power is not affected by pH, and it does not form halogenated organic compounds. Also, chlorine dioxide is more effective in attacking established bio-deposits.

However, ClO_2 is unstable and thus must be generated onsite. A common method for onsite generation is the reaction of sodium chlorite ($NaClO_2$) and chlorine in a slipstream fed to the cooling water, which proceeds as:

$$2NaClO_2 + Cl_2 \rightarrow 2ClO_2 + 2NaCl \quad (8)$$

Costs are usually several times higher due to the fact that more chemicals are required with onsite production than for straight halogen treatment.

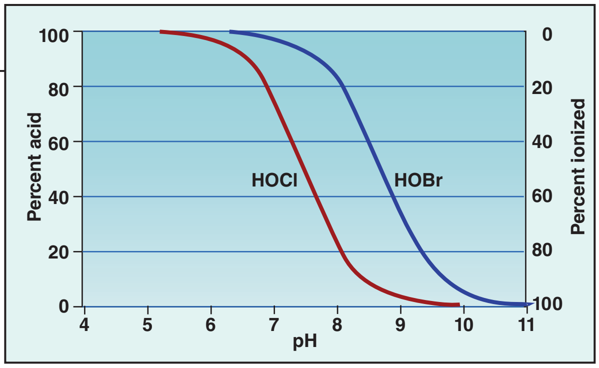

FIGURE 5. In this comparison of HOCl versus HOBr dissociation, note that the dissociation of HOCl occurs at a significantly lower pH compared to that of HOBr

TABLE 2. NON-OXIDIZING BIOCIDES

Chemical	Advantages	Disadvantages
2,2,-dibromo-3-nitrilopropionamide (DBNPA)	Fast acting, effective against bacteria, degrades quickly to non-hazardous byproducts.	Expensive, degrades quickly above pH 9, not very effective against fungi and algae.
Glutaraldehyde	Effective at high pH, effective against bacteria.	Degraded by oxidizing biocides.
Isothiozoline	Effective against bacteria and fungi. Works well with oxidizing biocides. Active over a wide pH range.	Skin sensitizer.
Quaternary amines	Effective against all organisms depending upon functional groups attached. Active over a wide pH range.	Can cause foaming. Careful handling required.

Other oxidants that have been tested for cooling water include hydrogen peroxide (H_2O_2) and ozone (O_3), but the short lifespan and tendency of these chemicals to escape from solution in the cooling tower typically make them ineffective in large cooling-water systems.

Another method to help control microbes is a supplemental feed of a non-oxidizing biocide. Typically, feed is needed on a temporary but regular basis, perhaps once per week. Table 2 summarizes some of the properties of the most common non-oxidizers.

Careful evaluation of the microbial species in the cooling water is necessary to determine the most effective biocides. From personal experience, I have seen very positive results with DBNPA on lake water supplies, but this chemical should not be considered a universal killing agent. Also, none of these chemicals should be used or tested without appropriate regulatory approval. They must fit in with the plant's National Pollutant Discharge Elimination System (NPDES) or equivalent guidelines.

Closing thoughts

As discussed in an earlier article by this author [*1*], CPI technical personnel sometimes focus on process chemistry without properly monitoring water/steam chemistry closely. Not only can improper monitoring and management of process chemistry engender excessive costs with regard to reduced heat transfer efficiency [*2*], but piping and steam-generator tube failures can also increase maintenance-related costs and may even lead to unscheduled process shutdowns, leading to additional cost escalations. ■

Edited by Suzanne Shelley

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These stainless-steel boilers are ideal for clean steam applications

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04 Plastics, Synthetic Resins
05 Drugs & Cosmetics
06 Soaps & Detergents
07 Paints & Allied Products
08 Organic Chemicals
09 Agricultural Chemicals
10 Petroleum Refining, Coal Products
11 Rubber & Misc. Plastics
12 Stone, Clay, Glass, Ceramics
13 Metallurgical & Metal Products
14 Engineering, Design & Construction Firms
15 Engineering/Environmental Services
16 Equipment Manufacturer
17 Energy incl. Co-generation
18 Other____________

JOB FUNCTION

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

EMPLOYEE SIZE

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

YOU RECOMMEND, SPECIFY, PURCHASE

(please circle all that apply)

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

1	16	31	46	61	76	91	106	121	136	151	166	181	196	211	226	241	256	271	286	301	316	331	346	361	376	391	406	421	436	451	466	481	496	511	526	541	556	571	586
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3	18	33	48	63	78	93	108	123	138	153	168	183	198	213	228	243	258	273	288	303	318	333	348	363	378	393	408	423	438	453	468	483	498	513	528	543	558	573	588
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13	28	43	58	73	88	103	118	133	148	163	178	193	208	223	238	253	268	283	298	313	328	343	358	373	388	403	418	433	448	463	478	493	508	523	538	553	568	583	598
14	29	44	59	74	89	104	119	134	149	164	179	194	209	224	239	254	269	284	299	314	329	344	359	374	389	404	419	434	449	464	479	494	509	524	539	554	569	584	599
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BUSINESS NEWS

PLANT WATCH

Dow plans to shut down its ethylene oxide and glycol plant in the U.K...

July 08, 2009 — The Dow Chemical Co. (Midland, Mich.) has announced its intention to close its ethylene oxide and glycol (EOEG) production facility at Wilton, U.K. by the end of January 2010. Several factors contribute to the decision, including the site's disadvantaged input costs. In addition, demand and profit margins for the site's outputs, particularly monoethylene glycol (MEG), began to soften in early 2008.

... and increases PP catalyst capacity in Louisiana...

July 7, 2009 — Dow Basic Plastics Licensing and Catalyst has increased capacity at its SHAC Catalyst plant in Norco, La. by 20%. SHAC catalysts are used in polypropylene (PP) production and are the preferred catalyst for licensees of the UNIPOL Technology.

Borouge is expanding polyolefins production

July 6, 2009 — Borouge, a joint venture between the Abu Dhabi National Oil Co. (Abu Dhabi, U.A.E.), and Borealis (Vienna, Austria), is expanding its production capacity of polyolefins in Abu Dhabi to 4.5 million metric tons per year (m.t./yr) by the end of 2013. Borouge has awarded the three main contracts for the front-end engineering and design (FEED) stage of its Borouge 3 expansion in Ruwais, Abu Dhabi to Tecnimont (Maire Tecnimont Group, Rome, Italy). This includes the FEED of the multiple polyolefin units, the LDPE (low density polyethylene) unit and the utilities and offsite facilities.

Topsøe contracts the world's largest ammonia plant

July 2, 2009 — Haldor Topsøe A/S (Lyngby, Denmark) will supply ammonia synthesis technology to Perdaman Chemicals and Fertilizers (Perth, W. Australia). With a capacity of more than 3,500 m.t./d, this ammonia plant will be the world's largest. The ammonia synthesis loop will be part of Perdaman's A$3.5-billion Collie Urea Project to develop a plant in W. Australia that will transform subbituminous coal into urea. The urea plant's capacity will be 2-million m.t./yr of urea, with a scheduled startup in 2013.

BASF to reduce polystyrene capacity in Europe

June 30, 2009 — BASF has announced the closure of one polystyrene plant at its Ludwigshafen site. The plant, which has been out of operation since mid-April, will be dismantled. This closure will reduce BASF's polystyrene production capacity in Europe by 80,000 m.t./yr to 540,000 m.t./yr or about 15%. The main reason for the shutdown is a decrease in demand.

Lanxess postpones Singapore production until 2014

June 29, 2009 — Due to the continuing global economic crisis, Lanxess AG (Leverkusen, Germany) is postponing the construction of its new butyl rubber facility in Singapore. Production is now scheduled to start in 2014. The 100,000-ton/yr plant, which would have cost up to €400 million to build, had been due onstream in 2012.

SNF plans new polymers plant in Louisiana

June 25, 2009 — SNF Holding Co. (Riceboro, Ga.) has announced its plans to construct a new facility for the manufacture of water-soluble polymers in Iberville Parish, La. The proposed facility is expected to be built in phases over five years, with a total capital investment of approximately $350 million. The initial target capacity is 250,000 ton/yr of polyacrylamide. Construction will begin after the company has secured the necessary regulatory permits, and the company is hopeful that a 1st Q 2010 construction startup is attainable, with a plant startup expected to occur approximately one year after construction begins.

MERGERS AND ACQUISITIONS

Rhodia enters into the biogas market

July 6, 2009 — Rhodia (Paris) has announced its first business development investment in biogas technology, by acquiring Econcern Group's participation in six pilot-scale biogas-production projects located in China and Vietnam. The effective completion of the transaction is subject to certain closing conditions, including approval by the relevant antitrust authorities. It is expected to be finalized in the 4th Q of 2009.

Novasep adds upstream processing capabilities through Henogen acquisition

July 2, 2009 — Novasep (Pompey, France), a producer of active pharmaceutical ingredients (APIs) and purification technologies for the life science industries, has announced the acquisition of Henogen, a contract manufacturing organization offering bioprocess development and manufacturing services from the cell bank to the supply of clinical products. Financial terms of the transaction were not disclosed.

BASF reorganizes its Petrochemicals Division

July 1, 2009 — BASF SE (Ludwigshafen, Germany) has reorganized its Petrochemicals Division. In the new organization, the number of business units has been reduced from six to four. The new business unit Basic Petrochemicals Europe, headed by Dr. Uwe Kirchgäßner, comprises the businesses for cracker products and industrial gases as well as alkylene oxides and glycols in Europe. More details of the reorganization can be found on www.che.com.

Celanese unveils EVA Performance Polymers Business Unit

June 26, 2009 — Celanese Corp. (Dallas, Tex.) has announced that it will rename its AT Plastics Inc. business, a producer of ethylene vinyl acetate (EVA) copolymers and low density polyethylene (LDPE) resins, Celanese EVA Performance Polymers Inc. The name change was expected to occur on Aug. 1, 2009. The Celanese EVA Performance Polymers business includes traditional applications for EVA copolymers and LDPE resins, including flexible packaging, lamination products, hot melt adhesives, medical tubing and automotive parts. Emerging markets for EVA copolymers include pharmaceutical and medical products, the solar energy industry and agricultural applications.

Honeywell plans to acquire the RMG Group

June 26, 2009 — Honeywell (Morristown, N.J.) has signed a definitive agreement valued at approximately $400 million to acquire the Kassel, Germany-based RMG Group (RMG Regel + Messtechnik GmbH and all of its subsidiaries, together RMG). RMG will be integrated into Honeywell Process Solutions. The transaction is subject to regulatory approvals. RMG specializes in the design and manufacture of natural gas control, measurement and analysis equipment including flow metering technology, regulating products and safety devices for oil and gas companies and has estimated 2009 sales to be $290 million. ■

Dorothy Lozowski

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

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Economic Indicators

2009 2008

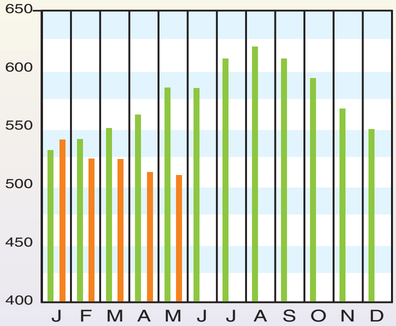
DOWNLOAD THE ***CEPCI*** TWO WEEKS SOONER AT ***WWW.CHE.COM/PCI***

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	May. '09 Prelim.	Apr. '09 Final	May. '08 Final
***CE* Index**	509.2	511.7	583.9
Equipment	596.8	600.4	710.3
Heat exchangers & tanks	529.9	534.2	712.4
Process machinery	583.2	584.9	644.3
Pipe, valves & fittings	748.1	752.5	835.6
Process instruments	389.0	390.1	445.6
Pumps & compressors	896.7	897.5	862.1
Electrical equipment	458.9	460.2	453.8
Structural supports & misc	602.4	609.0	770.6
Construction labor	326.9	326.5	319.7
Buildings	485.4	487.9	504.8
Engineering & supervision	347.9	348.5	353.7

Annual Index:

2001 = 394.3
2002 = 395.6
2003 = 402.0
2004 = 444.2
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4

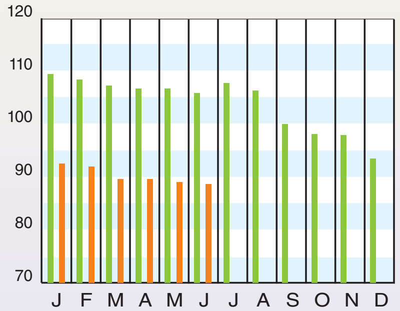


Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics

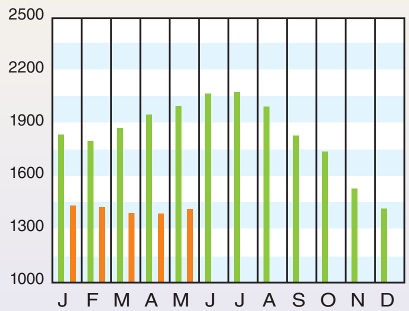
CURRENT BUSINESS INDICATORS

	LATEST		PREVIOUS		YEAR AGO
CPI output index (2000 = 100)	Jun. '09 = 88.7	May. '09 = 89.0	Apr. '09 = 89.6	Jun. '08 = 105.9
CPI value of output, $ billions	May. '09 = 1,418.9	Apr. '09 = 1,394.1	Mar. '09 = 1,394.7	May. '08 = 2,003.0
CPI operating rate, %	Jun. '09 = 65.0	May. '09 = 65.1	Apr. '09 = 65.3	Jun. '08 = 77.6
Producer prices, industrial chemicals (1982 = 100)	Jun. '09 = 229.8	May. '09 = 218.8	Apr. '09 = 218.3	Jun. '08 = 295.3
Industrial Production in Manufacturing (2002=100)*	Jun. '09 = 93.8	May. '09 = 94.3	Apr. '09 = 95.4	Jun. '08 = 111.0
Hourly earnings index, chemical & allied products (1992 = 100)	Jun. '09 = 148.2	May. '09 = 147.1	Apr. '09 = 146.1	Jun. '08 = 140.8
Productivity index, chemicals & allied products (1992 = 100)	Jun. '09 = 129.0	May. '09 = 129.4	Apr. '09 = 129.3	Jun. '08 = 131.1

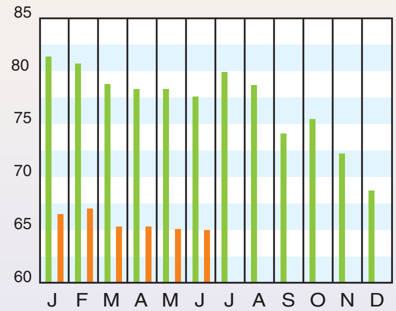
CPI OUTPUT INDEX (2000 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



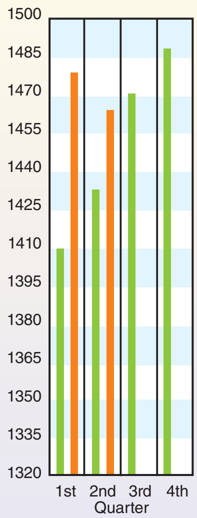
*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
Current business indicators provided by Global insight, Inc., Lexington, Mass.

MARSHALL & SWIFT EQUIPMENT COST INDEX

(1926 = 100)	2nd Q 2009	1st Q 2009	4th Q 2008	3rd Q 2008	2nd Q 2008
M & S INDEX	1,462.9	1,477.7	1,487.2	1,469.5	1,431.7
Process industries, average	1,534.2	1,553.2	1,561.2	1,538.2	1,491.7
Cement	1,532.5	1,551.1	1,553.4	1,522.2	1,473.5
Chemicals	1,504.8	1,523.8	1,533.7	1,511.5	1,464.8
Clay products	1,512.9	1,526.4	1,524.4	1,495.6	1,453.5
Glass	1,420.1	1,439.8	1,448.1	1,432.4	1,385.1
Paint	1,535.9	1,554.1	1,564.2	1,543.9	1,494.8
Paper	1,435.6	1,453.3	1,462.9	1,443.1	1,400.0
Petroleum products	1,643.5	1,663.6	1,668.9	1,644.4	1,594.4
Rubber	1,581.1	1,600.3	1,604.6	1,575.6	1,537.5
Related industries					
Electrical power	1,394.7	1,425.0	1,454.2	1,454.4	1,412.8
Mining, milling	1,562.9	1,573.0	1,567.5	1,546.2	1,498.9
Refrigeration	1,789.0	1,807.3	1,818.1	1,793.1	1,741.4
Steam power	1,490.8	1,509.3	1,521.9	1,499.3	1,453.2

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

Monthly declines in equipment prices softened between April and May, and preliminary estimates for the June CEPCI indicate that there was a slight increase between May and June. CPI output is also up over the previous month, but the CPI operating rate still hovers around the low point at 65% — an indication that many plants continue to shed built-up inventory.

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