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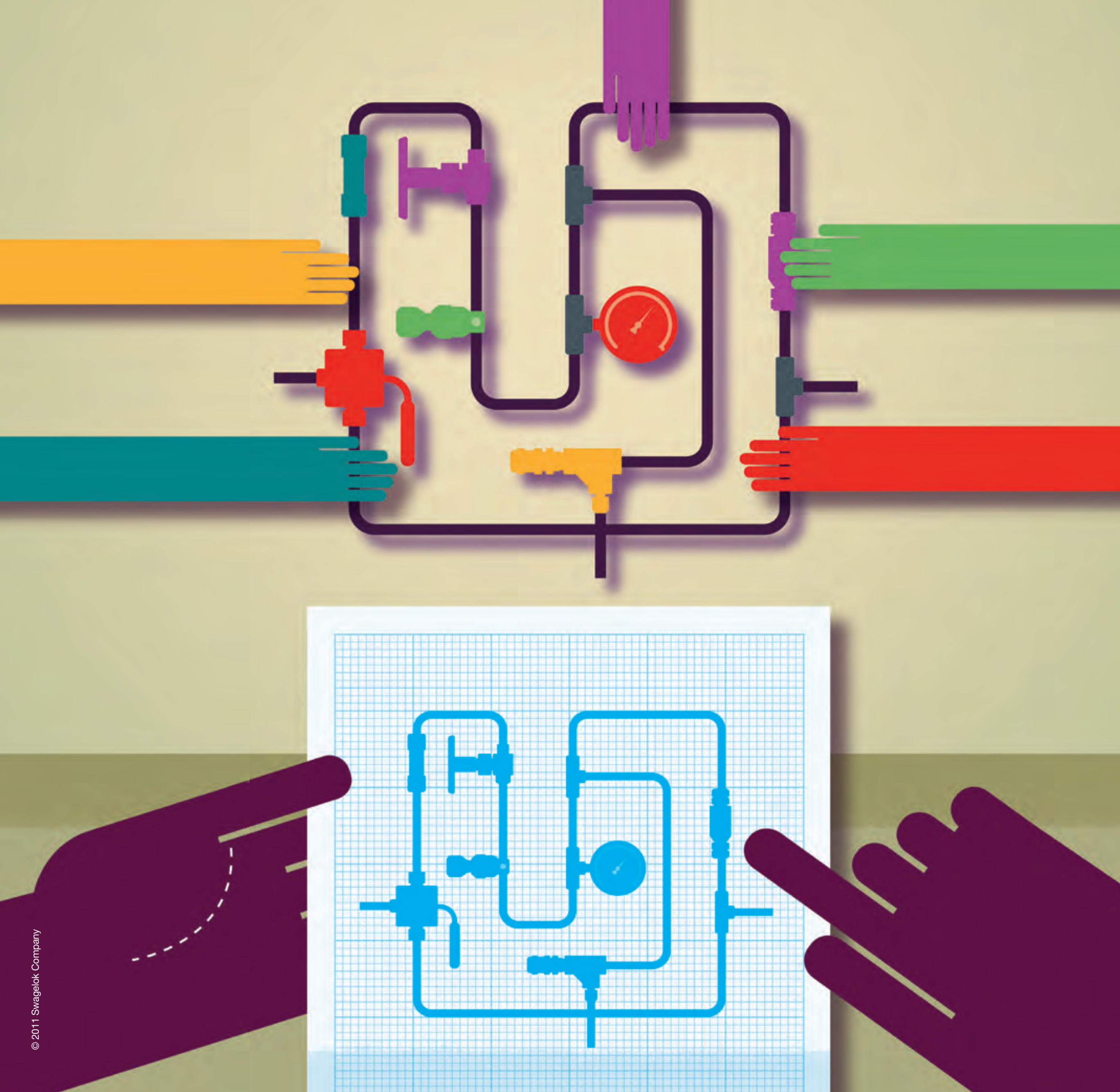

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## Editor's Page

# Perkin Award reflects ChE trend

Last month, at a dinner at the Hyatt Hotel in Philadelphia, Pa., the SCI America International Group (Philadelphia, Pa.; www.soci.org), presented its Perkin Medal to Dr. Rodney H. Banks, a research fellow at Nalco (Naperville, Ill.; www.nalco.com). As Stephanie Burns, honorary president of SCI explains, "This award recognizes his fundamental contributions to new sensor technologies that have led to improved water and energy efficiencies for a variety of industries."

In the mid-1980s, Banks and his co-workers at Nalco identified the need for improved control of industrial water treatment and commercial processes. He and colleague John Hoots subsequently led the invention and commercialization of TRASAR fluorescent tracing technology. When *Chemical Engineering* covered the introduction of the TRASAR in the November 21, 1988 issue, the technical description read like this: "In the original Nalco technique, a florescent tracer material — around 4 ppm of an organic disulfonic acid — is blended into the cooling water products and fed to the system. A 1–3 gal/min sample stream is continuously withdrawn and pumped at high velocity through a fluorometer that detects fluorescence. The amount of fluorescence measured is proportional to the amount of treatment chemicals."

During the past decade, Banks invented a broad suite of technologies incorporating chemical and mechanical sensors for intelligent monitoring and control of industrial water and process applications that have saved more than 300 billion gallons of fresh water at thousands of industrial locations around the world.

The current generation, 3D TRASAR automation technology has won a U.S. Presidential Green Chemistry Challenge Award for its cooling water application (*CE*, August 2008, p. 16). Its use is being expanded to a variety of additional applications, including boiler water treatment, membrane operations, papermaking and petroleum-refinery process applications.

In addition to TRASAR sensing and control, Banks has also created various electrochemical, optical, quartz-crystal microbalance-based sensors for not only chemical treatment levels but also for corrosion, scale and microbial fouling detection. These sensors detect system performance in realtime and allow tighter control of chemical treatments, increasing the longevity of equipment, improving process and worker safety, optimizing water and energy usage and minimizing impact on the environment.

Banks's recognition by SCI is notable for many reasons, but two float to the top of my list given the context of this readership. The first is the nod that this award gives to the growing importance of water supply and reuse overall.

Meanwhile, I find it worth pausing to reflect on the fact that an award designed to highlight accomplishments in applied chemistry is honoring an individual who ultimately developed hardware designed to minimize the use of chemicals in the first place. After all, the award and its namesake commemorate the discovery of the first synthetic dye (the so-called Perkin mauve) by Sir William Henry Perkin in 1856, which was a significant step forward in organic chemistry that led to the birth of a major segment of the chemical industry (for more, see this page, October 2006).

My point is by no means a criticism of the honoree or the award itself. In fact, I applaud Banks and have a sense of gratification myself in the award choice. It reinforces an important realization that I rarely find in the general, non-ChE public: The little known fact that today's chemical engineering profession is nearly as much about minimizing the use of chemicals as it is about producing them. ■

*Rebekkah Marshall*

# Letters

## Process automation: PID versus MPC

In his article Today's Process Automation Worlds (*CE*, August 2011, pp. 30–38), Mr. Cecil Smith states that the derivative mode in a proportional-integral-derivative (PID) controller in automatic tuning would require model-based approaches to consistently tune the mode, and then he goes on to indicate that the statement itself raises another question: "Once a process model is available, why not use a single-loop MPC [model predictive control] instead of PID?".

MPC is NOT a substitute for regulatory controls. MPC for a single-loop is a Smith predictor, and that was invented over 20 years before the MPC; and the performance of a single-loop model-based controller just can't be better than that of a properly tuned PID.

It is important for your readers to understand that MPC is not a substitution for regulatory controls.

Best regards,

**Sigifredo NINO**
Sr. Process Control Consultant

**Author responds:**

Process testing is routinely used only in the two examples cited by Mr. Nino:

1. MPC as applied to multivariable interacting processes, usually in conjunction with optimization endeavors: PID proved to be ineffective for implementing changes proscribed by optimization, which spurred the development of MPC to completely replace PID for this purpose.
2. Smith predictor or dead-time compensator as applied to processes such as commodity paper machines. PID is retained, but dead-time compensation provides the improvement in control performance.

It is interesting that where process testing is being applied, model-based control either replaces or supplements PID.

Properly tuning PID is a challenge, a major factor being that PID is usually installed on slow processes, such as reactor temperatures where bumping the process for the purpose of tuning will not be tolerated for too long. We have known how to tune PID based on models from process tests since the late 1960s, but this has not become routine practice and probably never will.

Although not the primary market for today's commercial packages, MPC methodology is capable of regulatory control. PID relies on a simplistic predictor based on the current rate of change of the process variable. MPC relies on a model-based predictor. For valid process models, the latter delivers superior performance. For applications such as reactor temperature control, MPC may not be the answer (reaction mechanisms and heat transfer are nonlinear), but we will eventually have to come up with something that can meet the ever-increasing demands for improved control performance from the process chemists.

PID will continue to be used in over 90% of our loops. But for the demanding applications, it is time we start seriously thinking outside the PID box.

**Cecil L. Smith**

## Calendar

### NORTH AMERICA

**Interphex Puerto Rico.** Reed Exhibitions (Norwalk, Conn.). Phone: 203-840-4800; Web: interphexpuertorico.com
*San Juan, Puerto Rico* **October 20–21**

**Valves & Actuators 101 Course.** Valve Manufacturers Assn. (Washington, D.C.). Phone: 202-331-8105; Web: vma.org
*Rosemont, Ill.* **October 26–27**

**SHPE Annual Meeting.** The Society of Hispanic Professional Engineers (Los Angeles, Calif.). Phone: 323-725-3970; Web: http://conference.shpe.org/shpe2011
*Anaheim, Calif.* **October 26–30**

**54th Chemical Process Industries Exposition and Educational Conference.** International Exposition Co. (Westport, Conn.). Phone: 203-221-9232; Web: chemshow.com
*New York, N.Y.* **November 1–3**

**2011 International Year of Chemistry (IYC) $O_3$ Symposium on Stratospheric Ozone and Climate Change.** American Meteorological Soc., American Geophysical Union, American Chemical Soc. and others. Phone: 979-845-0910; Web: 2011-iyc-03.org
*Washington, D.C.* **November 7–10**

**Association of Laboratory Managers' 32nd Annual Conference.** Assn. of Laboratory Managers (Columbia, Md.). Phone: 800-985-7879; Web: labmanagers.org
*New Orleans, La.* **November 8–11**

**American Indian Science & Engineering Soc. National Conference.** American Indian Science & Engineering Soc. (Albuquerque, N.M.). Phone: 877-530-2680; Web: aises.org
*Minneapolis, Minn.* **November 10–12**

**72nd International Water Conference.** Engineers' Society of Western Pennsylvania (Pittsburgh). Phone: 412-261-0710, ext. 13; Web: eswp.com
*Orlando, Fla.* **November 13–17**

**Fabtech.** Fabricators & Manufacturers Assn. (Rockford, Ill.). Phone: 866-635-4692; Web: fabtechexpo.com
*Chicago, Ill.* **November 14–17**

**2011 Materials Research Soc. Fall Meeting.** Materials Research Soc. (Warrendale, Pa.). Phone: 724-779-3003; Web: mrs.org
*Boston, Mass.* **November 28–December 2**

**2011 Annual Scientific Meeting and Technology Showcase.** Soc. of Cosmetic Chemists (New York). Phone: 212-668-1500; Web: scconline.org
*New York, N.Y.* **December 8–9**

**Power-Gen International 2011.** Pennwell (Tulsa, Okla.). Phone: 918-831-9160; Web: power-gen.com
*Las Vegas, Nev.* **December 13–15**

**SOCMA's 90th Annual Dinner and Annual Membership Meeting.** SOCMA (Washington, D.C.). Phone: 202-721-4165; Web: socma.org
*New York N.Y.* **December 5**

**IFPAC 2012 — International Forum & Exhibiion for Process Analytical Chemistry.** IFPAC (Grayslake, Ill.). Phone: 847-543-6800; Web: ifpacpat.org
*Baltimore, Md.* **January 22–25, 2012**

## EUROPE

**Polymeric Protective Technical Textiles**. Smithers Rapra Technology Ltd. (Shropshire, U.K.). Phone: +44-1939-250383; Web: polymerconferences.com
*Cologne, Germany* **October 25–26**

**Using WirelessHart Communication in the Process Industries.** HART Communication Foundation (Austin, Tex.). Phone: 512-794-0369; Web: hartcomm.org
*Copenhagen, Denmark* **October 27**
*Rosenheim, Germany* **November 3**

**Thermoplastic Elastomers 2011.** Smithers Rapra Technology Ltd. (Shropshire, U.K.). Phone: +44-1939-250383; Web: ismithers.net/conferences/XTPE11/thermoplastic-elastomers-tpe-2011
*Brussels, Belgium* **November 8–9**

**International Solar Summit 2011.** Fraunhofer Institute for Solar Energy Systems (Freiburg, Germany). Phone: +49-761-4588-5150; Web: solar-summit-2011.org/cms/
*Freiburg, Germany* **November 14–15**

**Expoquimia.** Messe Barcelona (Tübingen, Germany). Phone: +49-7071-365-595; Web: expoquimia.com
*Barcelona, Spain* **November 14–18**

**Polymers for Medical Implants.** Smithers Rapra Technology Ltd. (Shropshire, U.K.). Phone: +44-1939-250383; Web: ismithers.net
*Dublin, Ireland* **December 6–7**

## ASIA

**15th International Plastics and Rubber Trade Fair (M-PLAS 2011).** Messe Düsseldorf North America (Chicago, Ill.). Phone: 312-781-5185; Web: mdna.com
*Kuala Lumpur, Malaysia* **November 9–12**

**Controls Instrumentation and Automation 2011** Singapore Exhibition Services Pte. Ltd. (Singapore). Phone: +65-6233-6638; Web: cia-asia.com
*Singapore* **November 22–25** ■

*Suzanne Shelley*

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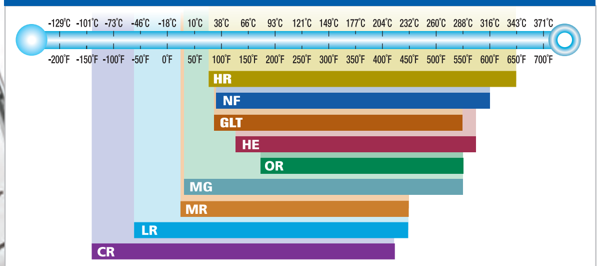


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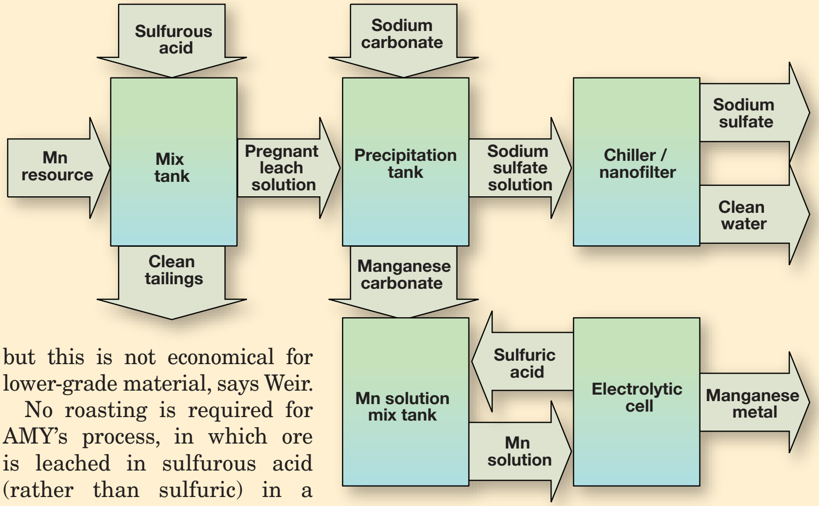
## U.S. production is scheduled for a critical metal




China produces about 98% of the world's electrolytic manganese metal (EMM), a vital ingredient used in specialty steels, aluminum and electronics. In contrast, the U.S. produces no EMM, says Nick Weir, an executive with U.S. American Manganese Inc. (AMY; White Rock, B.C., Canada; www.americanmanganeseinc.com). AMY plans to change that by using a patented hydrometallurgical process to extract the metal from its Artillery Peak Manganese Properties in northwestern Arizona. The company expects to produce EMM for $0.44/lb, versus $0.98/lb in China.

Like the Chinese processes, AMY's method is a modified and updated version of technology developed by the U.S. Government in World War II. The Arizona deposit consists of low-grade oxide material (2–7 wt.% Mn) that contains pyrolusite ($MnO_2$), psilomelane and other four-valent Mn oxides. High-grade oxide ore is typically subjected to high-temperature roasting to render the Mn leachable by sulfuric acid for electrolysis, but this is not economical for lower-grade material, says Weir.

No roasting is required for AMY's process, in which ore is leached in sulfurous acid (rather than sulfuric) in a stirred tank, followed by the removal of impurities. Aluminum, arsenic, most of the iron and silica are precipitated from the solution by raising the pH above 6, then zinc is removed by sulfide precipitation in a second purification stage. Mn is precipitated from the pregnant solution as manganese carbonate ($MnCO_3$) by mixing sodium carbonate with the solution. The $MnCO_3$ is then dissolved in recycled sulfuric-acid electrolyte for electrowinning.

In laboratory tests the process has obtained EMM of greater than 99% purity, says Weir. He adds that most of the water used in the process is recycled by precipitation and nanofiltration. AMY has started up a pilot plant of undisclosed capacity, which will operate until the late fall. Commercial production is scheduled to start sometime in 2014.

## A new approach to maintaining tubular heat exchangers

At the 2nd Annual ChemInnovations Conference and Expo (Houston; September 13–15), Hemi-O Technologies LLC (Corpus Christi, Tex.; dixonengineering@gmail.com) introduced its patent-pending technology that enables external access to individual tubes in a heat exchanger while the exchanger is in service and operating at full capacity. The so-called Hemi-O (heat exchanger maintenance and inspection — online) allows safe and leak-free physical isolation of, and external access to, each and every tube, thereby enabling tube I.D. cleaning, tube inspection and testing; and plugging of failed or failing tubes — all performed online using conventional methods for cleaning, inspecting and plugging.

"This technology will allow an end-user to be far more proactive in maintaining their exchangers from both a heat transfer perspective and from a condition monitoring perspective, says president Chris Dixon, who invented the technology. Conventional maintenance is normally performed off line, which requires waiting for a plant turnaround or — for severe fouling — can lead to an unscheduled shutdown and associated costs. Benefits of online servicing include improved heat-exchanger efficiencies, reduced energy consumption and lower operating costs, says Dixon.

The Hemi-O technology can be applied to most tubular heat exchangers, such as shell-and-tube and air-fin heat exchangers and surface condensers. The technology centers around the installation of a modified exchanger end plate (or channel cover) that is designed to have penetrations through it with integral valves and seal assemblies. The valve and seal systems allow for leak-free insertion of tubular isolation lances that mate-up with each of the tube ends at the tubesheet, while the heat exchanger is online and operating normally. Once the lances are engaged and sealed at either end of the tube, then that tube can be de-pressured and de-inventoried to a safe location. Once de-pressured and de-inventoried, the lance end valves, which are outside the

(Continues on p. 12)

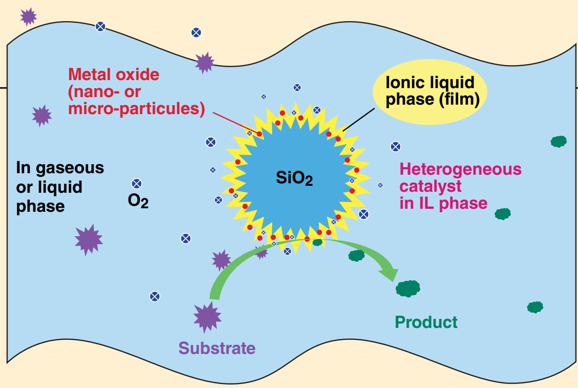
### Renewable jet fuel

Houston-based bioenergy company Terrabon Inc. (www.terrabon.com) has been awarded a $9.6-million, 18-month contract from Logos Technologies (Arlington, Va.; www.logos-technologies) to produce 6,000 L of renewable jet fuel for the Defense Advanced Research Products Agency (DARPA; Arlington, Va.; www.darpa.mil) using its MixAlco biorefining process. The MixAlco process converts nonsterile, nonfood biomass to organic acids, alcohols, ketones and other chemicals that can be further processed into renewable hydrocarbon fuels. The customized production process, to be constructed at Terrabon's Bryan, Tex. demonstration facility, employs proprietary Terrabon technology that allows the non-sterile anaerobic diges-

(Continues on p. 13)

*Note*: For more information, circle the 3-digit number on p. 78, or use the website designation.

# A new heterogeneous catalyst for low-temperature VOC decomposition




Professor Yuki Taniguchi at the Chemicals Research Institute, Tokyo Institute of Technology (Japan, www.res.titech.ac.jp/~gosei/taniguchi/index.html) has developed a new catalyst system that decomposes volatile organic compounds (VOCs) at lower temperatures than that required by conventional catalysts. The SILP (supported ionic liquid phase) catalyst is composed of silica gel impregnated with an ionic liquid that contains dispersed nanoparticles of metal oxide (diagram). SILP can be dispersed in liquids for destroying dissolved VOCs, or can be packed in columns for scrubbing gas streams. In both cases, VOC destruction occurs at the IL film, which contains the nanocatalyst particles.

SILP uses oxides of vanadium or molybdenum, so the cost for the catalyst is expected to be 1/10th to 1/100th that of alternative precious-metal catalysts (Pt or Pd). SILP may also find applications as a less-expensive alternative to silver as an antibacterial agent.

Taniguchi's group has prepared nanoparticles of $V_2O_5$, for example, by decomposing a $V^{+4}$ complex in the ionic liquid solution. The catalytic performance of the $V_2O_5$ is then enhanced by impregnating these nanoparticles into the pores of $SiO_2$. In laboratory trials on styrene decomposition, Taniguchi demonstrated that *n*-butyl-pyridinum trifluoroacetate ($[BuPy]CF_3CO_2$) or imidazorium tetrafluoro borate $[BuMeIm]BF_4$ was most effective as ionic liquid component, and vanadium and molybdenum are effective as metal components. The $[BuMeIm]BF_4$ system showed better performances at lower temperatures (around 100°C). The researchers are now investigating the decomposition of other chemicals, such as aliphatic compounds, aldehydes, $NH_3$ and other VOCs.

## HEAT EXCHANGERS

(*Continued from p. 11*)

exchanger, can be opened to the atmosphere to allow full access to the tube for cleaning and inspection.

A prototype system installed on a shell-and-tube exchanger was on display at the ChemInnovations exposition. The company plans to license the technology together with a servicing package, and is looking for partner companies to commercialize the technology, as well as operating companies for field testing.

## Making crude oil from coal, without mining or combustion

An underground coal-to-liquids (UCTL) technology is undergoing pilot testing at Oak Park, near Melbourne Australia, where a metric ton of brown coal is expected to yield about one barrel of oil suitable for use as refinery feedstock on an oil-parity price basis. UCTL takes place within the underground coal seam, whereby low rank coals are liquefied into crude oil substitute product at 300°C. Heat released from the reaction is returned to the surface as steam, which can be used to generate electricity.

The technology is subject to two patent applications lodged by its inventor, Peter O'Dowd, a consultant from South Australia. One patent covers the overall process, and the second covers the delivery of water with simulated supercritical properties (WSSP). This is water with high kinetic energy delivered using a jet pump and purpose-designed nozzles. Regal Resources Ltd. (Melbourne, Australia; www.regalresources.com.au) has exclusive worldwide rights to commercialize the process.

The UCTL process requires no direct mining or coal combustion. It utilizes high-pressure water and catalysts to produce hydrocarbon liquids, methane and steam from coal through drill holes. Small quantities of non-toxic initiation chemicals and catalysts are introduced into the coal seam creating an exothermic reaction, which increases the temperature to over 300°C. As the temperature approaches 300°C, the initiation chemicals are gradually replaced with WSSP and the liquefaction of the coal continues. The company says the effectiveness of the WSSP can be up to 200 m from the nozzle.

Conversion of coal to oil using supercritical water is a proven process. WSSP replicates supercritical properties by using high velocity instead of high pressure.

The pilot plant aims, among other things: to produce long chain hydrocarbons suitable for processing in existing petroleum refineries without modification; to compare UCTL liquids-to-gas ratio to that produced under ideal conditions whereby 95% liquids and 5% gas can occur; to confirm that there is a low percentage of $CO_2$ emissions, as compared with underground coal gasification that occurs at temperature above 1,000°C and which produces a higher proportion of $CO_2$.

(*Continued from p. 11*)

tion of feedstocks, such as municipal solid waste, sewage sludge, woodchips and others, to occur at low cost.

### Organic solar cells

Last month, Konarka Technologies (Lowell, Mass.; www.konarka.com) formed strategic alliances with several German companies to integrate its organic photovoltaic (OPV) technology into building facades. ThyssenKrupp Steel Europe AG (Duisburg, Germany; www.thyssenkrupp-steel-europe.com) plans to integrate Konarka's cells into steel roof and facades, thereby producing a multifunctional as well as an aesthetic product, which encases the building and produces solar power. The roll-to-roll production process Konarka uses (see *CE*, February 2008, p. 17–20) is similar to the established Coil-Coating process of ThyssenKrupp Steel Europe. The development will be based on PowerPlastic, a

(*Continues on p. 16*)

## A high-performance electrode material for lithium-ion batteries

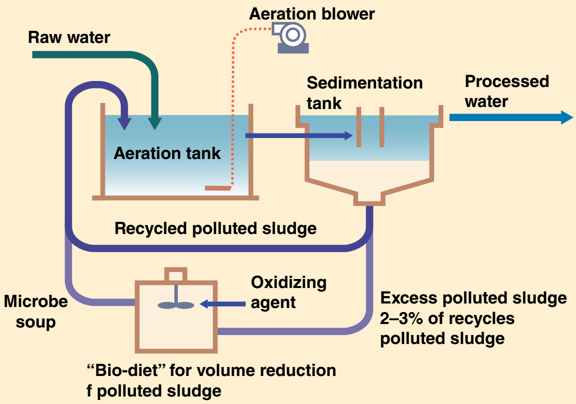
A huge market for lithium ion batteries is expected to develop as car makers move toward electric vehicles. However, improvements in the batteries' energy and power density are needed. It is also desirable to replace the common, high-cost lithium cobalt oxide cathodes with those based on more abundant and more environmentally friendly materials.

Now, a group from the Dept. of Energy Engineering, Hanyang University (Seoul, South Korea; www.hanyang.ac.kr) and the Dept. of Chemistry, University of Rome Sapienza (Rome, Italy; www.uniroma1.it), believes it has developed high-performance electrode materials that fulfill the requirements expected of advanced energy-storage systems. The group uses a combination of a stable, high performance Sn-C anode with a morphologically and structurally optimized $Li[Ni_{0.45}Co_{0.1}Mn_{1.45}]O_4$ cathode.

The cathode is made by a coprecipitation method, which uses stoichiometric proportions of high-purity $NiSO_4{\cdot}6H_2O$, $CoSO_4{\cdot}7H_2O$, and $MnSO_4{\cdot}5H_2O$ as the starting materials for the synthesis of $[Ni_{0.225}Co_{0.05}Mn_{0.725}](OH)_2$. An aqueous solution of the starting materials with a concentration of 2.4 mol/L is pumped into a continuously stirred tank reactor under a $N_2$ atmosphere. Simultaneously, an aqueous solution of NaOH (4.8 mol/L) and the desired amount of $NH_4OH$ solution are separately pumped into the reactor. The concentration of the solution, pH, temperature, and stirring speed are carefully controlled. The precursor powders are then recovered by filtration, washed and dried overnight. The cathode crystal is prepared by mixing LiOH and $[Ni_{0.225}Co_{0.05}Mn_{0.725}](OH)_2$ with a molar ratio of 1:2, followed by heat treatment at 850°C for 20 h in air. Prior to full lithium-ion-cell assembly, the Sn-C electrode is prelithiated by a surface treatment. This is done by placing the electrode in direct contact with lithium foil wet by the electrolyte solution for 180 min.

The group says it demonstrated that a Sn-C composite may operate in lithium cells with several hundred cycles, without capacity decay and with discharge-charge efficiency approaching 100%. With its treatment, the group verified an irreversible capacity of 63% in the first cycle, after which the electrode assumed the expected steady-state behavior — a stable reversible capacity of about 500 mAh/g.

The response of a cathode made of lithium manganese spinels in lithium cells is strongly influenced by the particle size and by the presence of doping metals. The group addressed these issues by doping $LiMn_2O_4$ spinel with Ni and Co and by preparing the resulting cathode with particles at micrometric size and using a metal ratio that is expected to provide high working voltage and high rate capability.




## Slash sewage-sludge volumes with this add-on digester

A 60% reduction in the sludge volume was achieved at the sewage treatment plant of Noboribetu City, Hokkaido, Japan, after installing a Bio-Diet SBD-1200 system from Nippon Steel Kankyo Engineering Co. (NSKE; Tokyo, www.nske.co.jp). The demonstration unit, developed at the Wakayama Cleanup Center of Noboribetu City, was tested during the summer.

In the Bio-Diet system (diagram), polluted sludge from the sedimentation tank is continuously fed to a side reactor, where a proprietary oxidizing agent is added to destroy the cell walls of microbes in the sludge. The treated sludge is returned to the aeration tank, where the biochemical oxygen demand (BOD) is then reduced through aerobic digestion. The Bio-Diet system is said to "drastically reduce" the cost for processing polluted sludge, and offers low installation cost, is easy to operate, requires no dewatering and has no adverse effect on processed-water quality.

The company says Bio-Diet is especially suited to treating polluted sludge with relatively low levels of inorganic compounds, and can be applied to treating wastewater from a wide range of the chemical process industries, including food, beverage, brewing, chemical, oil-and-fats, dying and fiber industries. The company is initially targeting applications only in Japan.

## A fast way to recover $CO_2$

A rapid pressure-swing-adsorption (rPSA) system to separate carbon dioxide from fluegas is being developed by W.R. Grace & Co. (Columbus, Md.; www.grace.com) and three partners under a $3 million grant from the U.S. Dept. of Energy (DOE; Washington, D.C.; www.energy.gov). The goal is to develop a process that costs half as much as current amine systems, whose cost is $50–70 per ton of $CO_2$ captured, says Rob Harding, Grace's director of global R&D for materials and packaging technology.

Grace is developing a multiple-bed rPSA system that cycles in 1–30 s, or more than 10 times the speed of conventional PSA, says Harding. $CO_2$, approximately 10–12% of the fluegas, will be adsorbed by one unit while another is desorbing. The $CO_2$ output gas stream will be >95% $CO_2$. The high cycle rate promises to reduce the size and cost of the equipment to a small fraction of that of conventional PSA units, he says.

One challenge is to develop an adsorbent tailored for

(*Continues on p. 16*)

# Dewatering enzymes boost ethanol production efficiency

A technique that improves the efficiency of ethanol plants by lowering the cost of dewatering the byproduct stillage (a slurry of corn solids and water) from the fermentation process has been developed by scientists at the U.S. Department of Agriculture's (USDA) Eastern Regional Research Center (Wyndmoor, Pa.; www.ars.usda.gov). The process has been demonstrated at full scale in a commercial plant operated by Center Ethanol Company (CEC; Sauget, Ill.).

CEC produces 50-million gal/yr of ethanol from corn and 172,000 ton/yr of dried distillers grains with solubles (DDGS), used for animal feed. Like other ethanol producers, CEC separates the ethanol from the solids, which are then dewatered sequentially by centrifugation, evaporation and drying to obtain DDGS.

The USDA procedure improves dewatering by adding enzymes to the fermentation process. In the tests, performed on six 750,000-gal fermenters, the researchers added a cocktail of commercial cellulase enzymes supplied by Genencor (Rochester, N.Y.) using 1 lb of enzymes per 1,000 lb of corn. The enzymes break down the fibrous material (mostly hemicellulose) in the solids, thereby disrupting their water-binding ability, says scientist David Johnston.

In the tests the enzymes improved centrifugal water recovery by 14%, with a corresponding 14% reduction in the gas requirement for the dryer. Johnston says the procedure requires essentially no modification to the process. He adds that Genencor and another enzyme supplier are now working on enzyme preparations specifically designed for this application.

(*Continued from p. 13*)

solar module from Konarka with a photoreactive polymer that, when dissolved, can be applied to various substrates.

In addition to their integration into steel facades, the organic cells will also be integrated into glass facades. Together with Bischoff Glass Technik AG (Bretten, German; www.bgt-bretten.de), Konarka is planning to develop (within the scope of a pilot project) glass-glass modules for building integration. The connections for the modules come from Lapp Kabel (Stuttgart, Germany; www.lappkabel.com), and the modules will be characterized by the Fraunhofer Institute for Wind and Energy System Technology (Bremerhaven; Germany; www-cwmt.cwmt.fraunhofer.de).

**RECOVER $CO_2$** (*Continued from p. 15*)

rapid cycling. Grace is working with zeolite materials, such as 13X and 5A, says Harding. Another challenge is to develop equipment that has high-speed valves. "Existing valves can be operated at that speed," he says, "but we need more robust valves and may have to change the geometry of the equipment." Grace's partners are Battelle (Columbus, Ohio), Catacel Corp. (Garrettsville, Ohio) and the University of South Carolina (Columbia, S.C.), which has expertise in PSA.

## Air-operated AES

Launched last month, the 410 Microwave Plasma Atomic Emission Spectrometer (MP-AES) from Aligent Technologies Inc. (Santa Clara, Calif.; www.agilent.com) is said to be a breakthrough in elemental analysis because the unit runs entirely on air for nebulization. Normally AE spectrometers use flammable (acetylene, ethylene or $H_2$) or expensive (Ar) gases to nebulize samples. Instead, the 410 MP-AES features a magnetically excited microwave plasma source that operates on nitrogen, which provides improved linear dynamic range, superior detection limits (down to sub parts per billion) and faster measurement compared with flame atomic-absorption spectroscopy, says the company. No longer requiring gas supplies, the unit is especially suited for remote sites and mobile laboratories, and since flammable gases are no longer required, the unit can safely perform, unattended, multiple-element samples overnight. ❒

# Waste-to-ethanol plant on pace for mid-2012 operation

Impending standards requiring that cellulosic ethanol be used in gasoline blending have focused attention on building a capacity for bioethanol from non-food sources. In a development that may begin to meet that need, a plant employing a unique method for fermenting synthesis gas (syngas) to produce ethanol will begin commercial operation in the second quarter of 2012.

According to its builder, Ineos Bio (Lisle, Ill.; www.ineosbio.com), the first-of-its-kind plant, located in Vero Beach, Fla., will use a variety of waste biomass as feedstock, and is expected to generate 8-million gal/yr of bio-based ethanol. In the Ineos process, biomass obtained from a nearby landfill is gasified to produce syngas, which is then fermented into ethanol by a specially cultivated, naturally occurring species of *Clostridium* bacteria.

"We spent considerable time and effort to precisely determine the process conditions and nutrient mix under which these bacteria produce ethanol in high yields and with high selectivity," comments Mark Niederschulte, Ineos COO. The continuous fermentation process has been demonstrated to occur quickly (within 10 min), Niederschulte says), allowing efficient operation. Another key engineering challenge for Ineos was achieving reliable operation of the gasifier, without producing high levels of $CO_2$ and tar, Niederschulte says, noting "the efficient use of feedstock is critical."

The plant will also produce electricity by using excess heat from the gasifier to generate steam for turbines. The facility will generate 6 MW of electricity, of which 4 MW will be used to run the plant, and 2 MW will be exported to power surrounding homes. By co-generating its own power and using no-cost waste feedstock, Ineos believes its operating costs will be significantly lower than those of corn- and sugarcane-based ethanol plants. The company is working to lower capital costs, which are now higher than conventional ethanol facilities. In addition to operating its plant, Ineos seeks to license its ethanol technology. ■

# COMPACT REACTORS BOOST PRODUCTIVITY

Scott Jenkins

## Velocys' microchannel reactors for production of synthetic fuels wins 2011 Kirkpatrick Award

**FIGURE 1. Velocys commercial director Jeff McDaniel (middle) accepted the 2011 Kirkpatrick Award from *CE* managing editor Dorothy Lozowski (left) and *CE* editor-in-chief Rebekkah Marshall (right) at a September 12 reception in Houston**

Velocys Inc. (Plain City, Ohio; www.velocys.com), a part of the Oxford Catalyst Group (Abingdon, U.K.; www.oxfordcatalysts.com), has been awarded the Kirkpatrick Award for Chemical Engineering Achievement from *Chemical Engineering*. The company's winning technology features microchannel reactors for producing synthetic fuels. The award was announced at a reception September 12 in Houston. The reception kicked-off the ChemInnovations 2011 Conference and Expo, held at the George R. Brown Convention Center. Velocys commercial director Jeff McDaniel accepted the award on the company's behalf. "It's an honor to receive the award," said McDaniel, explaining that a great deal of work by many people had gone into the technology, which allows faster processing in a range of reactions.

The Velocys technology was selected from a group of four award finalists, who were also honored at the reception. With its win, Velocys joins a distinguished group of companies to have received the biennial award, which was first handed out by the magazine in 1933. Past winners include BOC Group's low-temperature NOx absorption out of fluegases (2001), Amoco Chemical's anaerobic treatment of process wastewater (1991), Tennessee Eastman Co.'s coal-based acetic anhydride (1985), DuPont's hollow-fiber reverse osmosis (1971), Dow Corning's silicone products (1955), Dow Chemical's magnesium from seawater (1941) and Carbide & Carbon Chemical's petrochemical syntheses (1933).

The Kirkpatrick Award aims to honor the most noteworthy chemical engineering technology commercialized anywhere in the world during 2009 or 2010. Award nominations are collected and validated by the Kirkpatrick Award Committee Secretary, Rebekkah Marshall, who is *Chemical Engineering*'s editor-in-chief. Once it is verified that the nominee's technologies have actually been commercialized during the appropriate time period, they are submitted to a board of judges. The Kirkpatrick Award judges are all senior professors and department heads at accredited university chemical engineering departments in the U.S. and Europe, who are recruited to evaluate and rank the nominees based on a set of criteria that includes the technology's novelty, the difficulty of the chemical engineering problems solved, and the overall engineering excellence. The secretary tabulates the judges' scores to arrive at the winning technology.

### Microchannel reactors

The estimated ten trillion cubic feet of associated natural gas from oil wells that is either flared or reinjected yearly offers a vast market opportunity. Velocys and its parent company Oxford Catalysts has applied its microchannel-technology patent portfolio to that opportunity by developing a method for converting natural gas to liquid synthetic fuels. The microchannel technology could also be applied to biomass-to-liquids (BTL) and coal-to-liquids (CTL) technology. The reactors are designed for steam-methane reforming (SMR) of natural gas to form synthesis gas, followed by Fischer-Tropsch (F-T) synthesis to generate liquid fuels. The microchannel reactors are loaded with catalysts specially designed for microchannel use by Oxford.

Reactors using microchannel technology have parallel arrays of channels

## KIRKPATRICK AWARD HONOREES

The three other Kirkpatrick award finalists were also honored at the September 12 reception in Houston.

***Environ International Corp.*** (Arlington, Va.; www.environ-corp.com) was recognized for its system for biological treatment of volatile organic compounds (VOCs). The system utilizes existing biological wastewater-treatment facilities for destruction of biodegradable VOCs and other organic, hazardous air pollutants (HAPs). Environ's technology has been demonstrated at three U.S. petroleum-refining and chemical facilities, and the company has plans to extend the U.S. patent-pending treatment approach to eight additional facilities in coming months.

Environ developed the treatment method, known as VOC BioTreat, as an alternative to incineration or to systems involving activated-carbon VOC treatment. The VOC BioTreat protocol has demonstrated the ability to meet VOC and HAP handling requirements in U.S. state and federal emissions regulations.

VOC BioTreat works by piping VOC offgases into an existing wastewater-treatment tank that contains activated sludge at depths of greater than 18 ft. Microbes in the tank break down VOCs as they bubble up through the tank. VOC BioTreat can be retrofitted into existing wastewater treatment facilities for somewhat lower capital costs than those associated with installing thermal oxidizers or activated-carbon VOC-treatment systems, but the annual operating costs are less than 10% of those for conventional systems.

In addition to the VOC BioTreat technology, Environ has developed a test method to confirm the performance of the proprietary technology within a plant setting. The ability to reliably test for VOCs is critical for acceptance from the regulatory authorities, the company says.

The VOC BioTreat technology recently received the grand prize for research excellence in the American Academy of Environmental Engineers' E3 competition.

***NSR Technologies Inc.*** NSR (Decatur, Ill.; www.nsr-tech.com) has developed a "green" chemical pathway to potassium hydroxide (KOH) solution using membrane separations technology and ion-exchange chromatography. The manufacturing process, which yields 45–50% KOH solutions and 7% hydrochloric acid, is the first environmentally friendly, cost-effective alternative to electrolysis (chlor-alkali) in decades, NSR says. The process generates high-purity products free of mercury and oxidizing species. Also, it does not produce chlorine gas.

The strong base KOH is used for the manufacture of potassium-containing products, such as the food additive potassium citrate and the water-treatment agent potassium permanganate. It is also a key ingredient in soap and detergent processes, as well as agricultural fertilizers and pharmaceuticals.

NSR's process uses a multipass design that reduces the fluid recirculation requirements, allowing a smaller plant size and lower costs. The company also designed filter cells that minimized internal leaks and shunt/stray losses. Finally, NSR's chromatographic purification process removes 95–99% of the salt from cell-stack KOH product.

NSR's process consumes 40% less energy than a conventional process per unit of product manufactured.

***Invensys Operations Management***. Along with ConocoPhillips (Houston; www.conocophillips.com), Invensys Operations Management (Plano, Tex.; www.invensys.com) has developed a method for online monitoring of hydrofluoric acid (HF) catalyst in the production of octane. The non-spectroscopic method, called ACA.HF Alkylation Measurement Solution, lowers the cost of online HF monitoring while simplifying the measurement and reducing risk to plant workers.

To measure HF levels, the Invensys approach involves analyzing differential responses from online sensors. The system takes readings of water concentration from electrode-free, non-contacting conductivity sensors, as well as simultaneously measuring density and mass-flow levels with a Coriolis flowmeter. The company has developed specialized software to calculate HF levels from the readings.

HF alkylation is a widely used process to produce isooctane for blending into gasoline. In the process, HF catalyzes the reaction between isobutane and four-carbon olefins to form octane. There are three main components in the alkylation catalyst stream, Invensys explains: HF (usually around 90%); water (about 1%); and acid-soluble organic molecules (ASO; which make up the rest). "Tight control of these constituent concentrations, which can save millions of dollars per year, requires accurate monitoring of the levels of all three components," the company says. Using the formula %HF + %water + %ASO = 100%, the Invensys system can correct for temperature effects and for second-order influences of interactions between ASO and water.

Early approaches to HF monitoring involved manual samples and laboratory analysis, which offers limited accuracy and can expose laboratory workers to toxic substances. More recent Fourier-transform near infrared (FTNIR) techniques are very accurate, but their adaptation for realtime online monitoring is complex and costly, Invensys says.

The new HF monitoring system costs about half as much as an FTNIR system, and it requires minimal maintenance because its core components are built from rugged materials long-proven in industrial HF applications. The sampling system amounts to a continuously flowing sample from a slipstream of the process, Invensys says. "Based on established industry methods, estimated mean time between failures of the technology exceeds 29 years," the company adds. Additional advantages include minimized potential for corrosion and greatly reduced potential for plant and laboratory workers to be exposed to the sample.

The system's hardware is a sampling panel, located in the hazardous area, that contains all fluid-handling components, sensors and signal transmitters. Data are transmitted from the panel to a distributed control system (DCS), with which users interact via a human-machine interface in the nonhazardous area. ■

with sizes in the range of 0.1 to 5.0 mm in width. The smaller dimensions allow processes to accelerate by a factor of 10 to 1,000 by reducing the distances required for heat and mass transfer, thus decreasing the transfer resistance between process fluids and channel walls. As a result, system volumes can be reduced ten-fold or more compared to conventional hardware, such as fixed-bed or slurry-bed reactors.

A major advantage to microchannel reactors revolves around the greatly enhanced productivities compared to traditional plants that are enabled by the microchannels. The ability to boost productivity through distributed production — production carried out in small-scale plants located near the source of feedstocks, as well as near markets — has been made

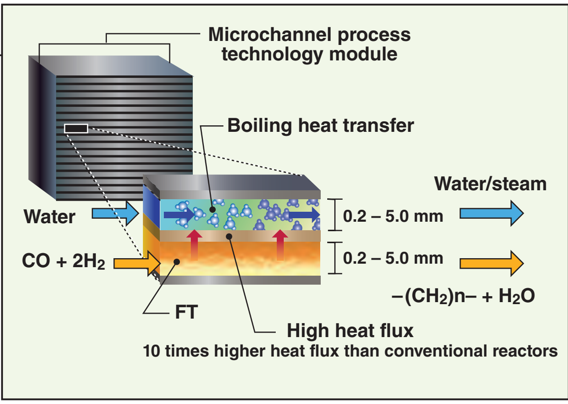



**FIGURE 2. The small dimensions of the microchannels promote favorable heat- and mass-transfer properties**

economically and practically feasible, Velocys says.

Because of their heat management properties, microchannels are ideally suited for carrying out catalytic reactions that are either highly endothermic (such as SMR) or highly exothermic (such as F-T synthesis). Velocys microchannel reactors "exploit rapid reaction rates and intensify processes by minimizing heat and mass transport limitations," the company says. Additional benefits result from the process efficiency afforded by the microchannels, as well as their smaller size, which saves on capital costs and space. The Velocys GTL system can scale the SMR and F-T processes to match associated and stranded natural gas resources at a particular site, both onshore and offshore. Possible products from the Velocys GTL system include diesel, jet fuel and naptha, as well as feedstocks for synthetic lubricants and waxes for specialty chemicals.

Aside from SMR and F-T chemistry, microchannel process technology could be applied in a wide variety of areas, Velocys says. These include thermal processing, such as ethane cracking and fuel processing; chemical production, such as ethylene oxidation, as well as separations, mixing and emulsification; gas processing; biological processes and multiphase systems.

Microchannel technology has experienced skepticism from industry over concern about plugging or fouling of the narrow channels. Velocys acknowledges that fouling is a concern, but has experimented with two interrelated strategies that help to mitigate the risk of plugging: high wall shear and good flow distribution. The ability of microchannel devices to handle solids is attributed to high wall shear that sweeps particles out instead of allowing them to build up, the company says. The Velocys team found that for devices with good flow distribution, no pressure-drop increases were observed, even when the feed water was doped intentionally with low levels of dissolved solids. Higher levels did cause fouling, similar to the case for plate-and-frame heat exchangers.

## Engineering and manufacturing

Among the major engineering challenges required to bring the microchannel technology into operation was to develop a reactor design capable of efficient and effective heat management in both exothermic and endothermic reactions.

In the case of the endothermic SMR reaction — in which natural gas is mixed with steam and passed over a catalyst to produce synthesis gas — Velocys scientists constructed a network in which the SMR process occurs in channels adjacent to those for heat-generating combustion of hydrogen gas. Heat-transfer properties of the microchannels increase the efficiency of the process. The M-shaped pattern of channels allows the reactor to have a cold end and hot end, which simplifies installation — all supports and manifolding are attached to the cold end, and the hot end is allowed to expand freely.

For the F-T reactor, the same heat-transfer properties are key, as the synthesis gas is converted to parafinnic hydrocarbons over a cobalt catalyst. Thousands of process channels filled with catalyst are interleaved with coolant channels, resulting in exceptionally high heat flux, Velocys says.

Another engineering challenge revolved around the manufacturing for the reactors. Velocys developed a new manufacturing process, known as laminate construction, in which photochemically machined shims are precisely stacked and joined by diffusion bonding, brazing or welding. The parallel microchannels are formed by interleaving thin sheets of formed material (shims) with solid sheets (walls).

Specially designed catalysts had to be designed as well, in order to maximize the benefits of the microchannels. Using Oxford's OMX method, a highly selective catalyst was developed with activities an order of magnitude higher than conventional catalysts. The proprietary OMX method uses an organic component in the calcination procedure to modify the catalyst properties such that the metal crystallites are of the optimum size to maximize activity, selectivity and stability for a given application. In demonstrations of the catalyst productivity, the Oxford catalyst achieved 1,500 kg/m$^3$/h, compared to productivities of 100 and 200 kg/m$^3$/h for conventional fixed-bed and slurry-bed reactors, respectively.

## Commercial activity

After successful demonstration of its GTL process at a facility in Güssing, Austria, Velocys is working on fulfilling commercial orders. One order comes from the Portugese company SGC Energia for a microchannel BTL facility. Another order comes from an integrated GTL facility in Brazil that includes both microchannel F-T and microchannel SMR. The Brazil plant is slated to start operation in Fall 2011. ■

*Scott Jenkins*

# FIXED GAS DETECTORS

## Advances to fixed gas-detection systems reliably alert you and make it easier to keep the devices in better working order to achieve high levels of safety

MSA

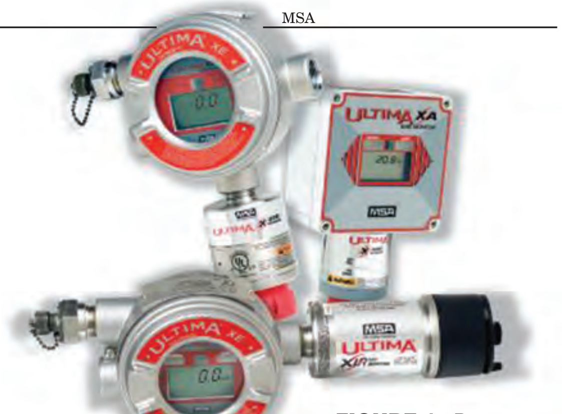



**FIGURE 1.** Processors are looking for gas detection devices that offer simplified maintenance, such as MSA's Ultima X Series of fixed monitors with a sensor disconnect-under-power feature that allows sensor change out without declassifying a hazardous area

Honeywell

**FIGURE 2.** This illustration of the "Intelligent Plant" showed the interconnectedness of gas monitoring with other systems such as video surveillance; flow, temperature and vibration monitors; transportation; fire and smoke; and other security systems, calling for a one system approach

When it comes to fixed gas-detection devices, there are a lot of choices available. And, wise chemical processors do not select this essential safety equipment based on price. Instead, for areas of the plant that require continuous monitoring for loss prevention and personnel protection, fixed gas-detection systems are chosen based upon reliability, flexibility and maintainability.

"While cost can be an issue, I find most chemical processors are willing to spend the money on this safety critical equipment if they perceive that it is technically superior and will offer the highest level of safety they are looking for," says Chris Lange, manager of marketing with Oldham, an Industrial Scientific company (Oakdale, Pa.). "They are not willing to sacrifice safety for cost savings. The risks are too high to make those kinds of sacrifices."

Fixed detection systems are chosen over portable ones in situations where the process requires protection 24 hours per day, seven days per week (24/7). These areas may include processes where equipment might fail or leak flammable or toxic material, says Steve Phelps, applications sales manager with Sensidyne (Clearwater, Fla.).

Tom Salapow, product group director for gas detection products with MSA (Cranberry Twp., Pa.), agrees. "Fixed gas detection devices are working 24/7 looking for leaks whether personnel is available or not at a particular location. Fixed detection provides a layer of safety that is transparent to the workers and it provides output that portable devices cannot," he says. "This output provides the ability to see what's happening inside the room before a person even enters the area so they will know there is a situation occurring and can take any necessary action from donning the appropriate gear to evacuation."

However, Lange adds that this does not mean portable detection systems are going the way of the wind. Instead, they are likely to be used in tandem with fixed monitors. Portables are still very useful tools for personal protection in situations such as confined-space entry and hot work, agrees Phelps. "There will always be a combination of the two because they complement each other," says Lange.

### Lower cost of ownership

Fortunately, gas detection providers are making this one-two punch easier to achieve thanks to advancements in their wares, especially when it comes to fixed detection. Equipment manufacturers are developing fixed gas monitors that offer a lower cost of ownership based upon features like flexibility, ease of installation, simplified maintenance and reliability.

### Flexibility in fixed detection

More and more of our customers see limitations with traditional fixed systems, explains Bobby Sheikan,

## A WIRELESS REVOLUTION?

It's no secret that wireless products, including fixed, wireless gas-detection devices, can save users substantial amounts of money in labor and material costs. Obviously, being wireless they eliminate the cost of additional conduit, as well as labor, installation and maintenance. The systems also offer additional flexibility because it is possible to completely surround a hazardous area with wireless gas detectors. And, many companies offer mesh wireless topographies that allow processors to use an installed wireless system to send messages from one node to another throughout the plant. If one node goes down, it automatically sends the message to a different node. This type of system is called "self-healing" and allows the detection to be very agile and very responsive.

For this reason wireless technology is starting to gain momentum in many industrial facilities. And because it's been around for a while, there are a lot of improvements in the technology regarding reliability and security.

However, the majority of applications in the chemical process industry remain in remote areas where it is difficult to get power to the site or difficult to run wiring back to a receiver. This is especially true when it comes to wireless gas detection. There's a tendency to not fully adopt digital protocols and wireless communication for safety critical items because users believe they need the reliability of a wired, analog system.

This doesn't mean that wireless gas detection is non-existent in chemical processing. Instead, it's often added to wired systems to supplement the capabilities of that system. Typically what is found are facilities with existing analog detectors combined with wireless systems on top to provide additional communication and capabilities.

So while wireless gas detection is not yet at the point where everyone wants to go 100% wire free, it is slowly making progress. And, as security of these systems continues to increase due to the now available mesh networks and encrypted, spread-spectrum, channel-hopping capabilities, not to mention younger engineers familiar and comfortable with wireless technology entering the workplace, it is likely that wireless gas detection systems will eventually replace hardwired systems in many locations. ❒

Honeywell

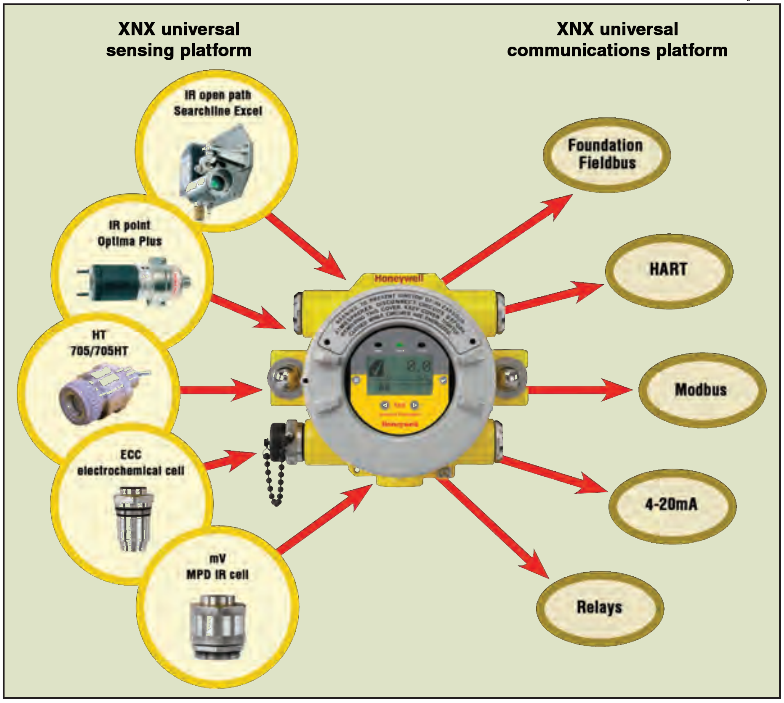



**FIGURE 3.** **This diagram illustrates the moduler product design that goes into a gas detector when designed by Honeywell for the widest range of installations, including the newly emerging SIL 2 and Foundation Fieldbus requirements. It shows the various sensing technologies that it can support (catalytic bead, electrochemical, infrared) so that it can detect the widest range of gases, and it shows the various communications technologies that it can support so that it can serve in a range of installation requirements**

director of product marketing with RAE Systems (San Jose, Calif.). "If one of the fixed detectors in an area goes down, they have to do maintenance, which can be disruptive and difficult," he says. So, RAE Systems has designed the MeshGuard, a semi-fixed system that can be applied to a process from a few days to a few years. "It is designed to behave like a fixed system, but has a wireless mesh radio that gives it a lot of flexibility that you don't have with a traditional fixed system," he says.

MeshGuard is rapidly deployable in industrial and remote monitoring applications and combines advanced gas-detection technology for industrial safety applications using the latest in connected data systems. Because the system contains wireless sensors that can be set up quickly in any environment, MeshGuard eliminates the need for lengthy and expensive installation projects. By detecting and recording a range of gases and quickly relaying the data to an easy-to-understand central system, safety personnel have access to up-to-date information from throughout the network of sensors.

Flexibility is also a key option with Oldham's OLCT 200 gas detection transmitter. This fixed detector is designed for use with multiple gas detection technologies, including electrochemical, catalytic-bead, infrared and photoionization detection sensors. This allows the unit to detect many typical gases and provides users with the ability to standardize on one transmitter for all of their detection needs. The unit is also capable of monitoring two different gases simultaneously, and provides the ability to mount sensors away from the transmitter and display for remote or difficult to reach locations.

The OLCT 200 is designed for application flexibility, according to Lange, as it is compatible with nearly any fixed gas-detection installation. It

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Sensidyne
www.sensidyne.com

can be configured for two- and three-wire, 4–20-mA analog output, Modbus RTU digital output, HART communication and wireless communication. The wireless capability provides the benefit of a completely wireless gas detection system that is compatible with Oldham's alarm controllers and mobile monitoring systems. (For more on wireless, see box on p. 24.)

### Simplified maintenance

Advanced features, such as simplified maintenance, also help today's fixed detection systems do their job while lowering cost of ownership. For instance, MSA's Ultima X Series of fixed monitors (Figure 1) offers a sensor disconnect-under-power feature that allows sensor change out without declassifying a hazardous area. "This feature provides access to the device in a potentially hazardous and dangerous environment without the inconvenience and expense of shutting down a whole process to perform maintenance," explains Allan Roczko, product line manager for fixed gas-detection products at MSA. And, interchangeable smart sensors are pre-calibrated, installation-ready and field-replaceable without tools. The single-board design also provides simplified serviceability. "This means the board can be easily removed and is self aligning," says Roczko. "So if you need to change the board, you simply pop it out and put a new one in and you're ready to go. This is a tremendous feature for simplified maintenance."

Honeywell

**FIGURE 4.** **Gas detection instrumentation can be made to interface with a handheld communicator, so operators can obtain information from the system or interrogate it, at its point of use. These tools simplify and speed maintenance tasks, so the operator can spend time more productively**

Similarly, Sensidyne offers the SensAlert Plus with advances including test-on-demand and predictive sensor-failure features. "While most sensors fail, ours are designed not to," says Phelps. "We have a predictive failure function that looks at cumulative gas exposure of the sensor, age of the sensor and how much calibration you've had to give it and then it sends a warning to the user that the sensor will need to be replaced before it actually fails."

While that feature significantly increases the reliability of this single-transmitter gas-detection system, the SensAlert Plus also provides a large LED display of the gas value and a backlit LCD displaying system settings, data review, sensor information and visual and audible alert annunciators.

## Beyond safety compliance

Don Galman, marketing communications supervisor with Honeywell Analytics (Lincolnshire, Ill.) suggests taking these features — and gas detection systems in general — a step beyond safety compliance. "We like to offer processors the potential to integrate safety equipment into other process-related equipment to provide a boost not only to safety compliance but to their efficiency and productivity as well," he says.

For example, he says controllers can serve as bridges between gas detectors or other safety instruments and some of the other process-related equipment, which makes safety just one component of the whole system design (Figures 2–4). It would work something like this: Honeywell's XLS3000 fire-alarm control panel takes input from gas detectors and links those inputs with controls and systems on the safety side. "Within a plant there are hazardous areas and safe areas," he explains. "The gas detectors are in the hazardous area, but by using a bridge like our fire-alarm control panel, the two areas are brought together for monitoring, which makes it both a cost- and time-efficient solution."

Another example would be installing a system that offers a fast response to a gas leak, tied into a suppression system, so that the system could be shut down to avert catastrophe before it occurs. "We offer products like the XNX Universal Transmitter for gas detection that help with trending and identification of system faults before they become apparent," says Galman. "The ability to identify what's going on before it happens, combined with the ability to react faster and make informed safety decisions, allows users to save money and time while increasing productivity and avoiding lawsuits."

Galman continues: "Safety should always be of the utmost importance, but there is no reason processors can't try to move toward a culture that embraces advances in gas detection devices, or other safety equipment, as just one aspect of a business boosting design." ■

*Joy LePree*

# A window into kettle reboiler secrets

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

Thermosiphon reboilers are the new standard in petroleum refineries and chemical plants. Nevertheless, approximately 50% of the world's reboilers are kettles. In the realm of heat transfer, kettle reboilers have not been understood well. Last month, at ChemInnovations, however, Pete Parker, FRI's president and my supervisor, cracked the knowledge barrier with insight from nothing other than windows.

FRI has a long successful history of employing windows on distillation columns. It was just a matter of time before FRI would add windows to one of its heat exchangers. Dr. Parker's presentation described how FRI installed windows on an industrial-size kettle reboiler. FRI's low-pressure reboiler includes about 200 U-tubes and employs steam within those tubes to boil hydrocarbons in a 3-ft-dia. shell. Professors Bell and Whiteley, of Oklahoma State University, consulted regarding the exact placement of the windows. Lucky Wilson, of the May edition of this column entitled "Low Cost Bidding", performed the cutting and the welding on the reboiler, which regularly operates as high as 165 psia. As far as we know, nobody has ever put windows on an industrial-size reboiler before.

The results debunk a host of theories, the first being this: We can see! Skeptics said that we would not be able to see anything worthwhile. They said that a washing machine bi-phase would totally obstruct our view of the tubes. They said that we would never see the tubes bubbling. But, they were wrong. We can see everything!

The FRI low-pressure reboiler routinely handles butanes, xylenes and $C_6/C_7$. Operating pressures range from 75 mm Hga to 165 psia. At the time of Parker's presentation, the kettle had been run with four different systems, but not xylenes at vacuum. Parker showed video footage that was taken through the new kettle windows. The footage was crystal clear — and clearly surprising. At low duties, bubbling did not begin on the tubes. It began instead on the vertical segmental baffles and on the horizontal support rods. At medium and at full duties, the most elevated tubes in the bundle were extremely active, and the lower tubes were normally inactive.

There were other surprises. Observed entrainment rates out the top of the kettle were far less than the predicted values. There appeared to be far more bubbling at the end of the kettle where the steam entered. As a result, there was a strong horizontal vapor vector above the boiling pool.

Tony Cai, of FRI, is presently developing two correlations for FRI's members. One correlation will provide the depth of the boiling pool as a function of the reboiler duty and the liquid product rate. The other correlation will provide a relationship between C factors and the onsets of high entrainment rates. (He should have completed these correlations by now, but I have not been able to tear him away from the video footage.)

At FRI we perform R&D. At the end of every R&D project every R&D engineer requests the same thing — more data. Along those lines, with the permission of the FRI membership, two additional windows will be added to the kettle reboiler in May of 2012. If you attend next year's ChemInnovations, Parker will have even more video footage to show you. ■

*Mike Resetarits*
*resetarits@fri.org*

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

# Steam generator operation and thermodynamics

A well-operated steam generator can save money. In a steam-driven turbine system, water is heated in the steam generator to produce high-temperature, high-pressure steam. Steam is then expanded in a turbine to produce electricity from a generator. Turbine steam is condensed back into water in the condenser. A pump then returns the water to the steam generator.

## Engine thermodynamics

Theoretically, the most efficient engine possible operates with a heat input ($Q_H$) at high temperature ($T_H$) and a heat discharge ($Q_L$) at low temperature ($T_L$) in which:

$$(Q_H/T_H) - (Q_L/T_L) = 0$$

This case represents an unattainable ideal engine, because energy losses — due to friction, heat escaping from the system, flow disturbances and a variety of other factors — are inevitable. Entropy is the property scientists have used to describe this degree of disorder.

Applying the concept to the situation in a steam generator and turbine system, the process cannot be made to do work without some extraction of heat from the process. In a conventional steam generator, $Q_L$ is the heat removed in the condenser. And since the efficiency of a Carnot engine is $\eta = 1 - (T_L/T_H)$, as the input temperature goes up or the exhaust temperature goes down, efficiency increases.

## Condenser performance

In a basic steam-generation system (Figure 1), the main purposes of the condenser are to condense the exhaust steam from the turbine for reuse in the cycle and to maximize turbine efficiency by maintaining proper vacuum. As the operating pressure of the condenser is lowered (vacuum is increased), the enthalpy drop of the expanding steam in the turbine will also increase. This will increase the amount of available work from the turbine. Lowering the condenser operating pressure will increase turbine output and overall efficiency, so it is advantageous to operate the condenser at the lowest possible pressure (highest vacuum).

An example calculation will help illustrate why turbine exhaust steam must be condensed rather than transported directly back to the boiler. Consider the system shown in Figure 1, in which the turbine is ideal (no frictional, heat or other losses — no change in entropy). The work done by the turbine can be found using the steady-state energy equation, $W_T = m\,(h_2 - h_1)$, where $W_T$ is turbine shaft work, m is mass flow into the system and $(h_2 - h_1)$ is the enthalpy change.

Turbines are typically around 80–90% efficient. Assume for the example that the input steam temperature is 1,000°F and the inlet pressure is 1,000 psia, and the output steam is atmospheric pressure (14.7 psia). The enthalpy (a measure of the available energy of the fluid) for steam and saturated liquid conditions such as this have been calculated, and are available in steam tables. From calculated data, the enthalpy of the turbine inlet steam for this system is 1,505.9 Btu per pound of fluid, and the enthalpy of the steam exiting the turbine is 1,080.9 Btu/lb of fluid. If the steam flow is 1 million lb/h and the steam quality is 93%, then the work done would be 124.5 MW.

If the system includes a condenser, the exhaust pressure would be reduced and the enthalpy of the turbine exhaust would be lowered to 923 Btu/lb. At the same steam flow as the previous example, the total work is 170.6 MW, a 37% increase from a system with no condenser.

From a physical perspective, the condensation process reduces the fluid volume by over 17,000 times. The condensing steam generates the strong vacuum in the condenser, which acts as a driving force to pull steam through the condenser.

What about cases where waterside fouling or scaling causes the condenser pressure to increase from 1–2 psia? Calculations show that the work output of the turbine drops from 582 to 546 Btu/h, or 10.6 MW of work. This is a primary reason why proper cooling-water chemical treatment and condenser performance monitoring are so important.

**FIGURE 1.** A basic steam-generation system with isentropic turbine

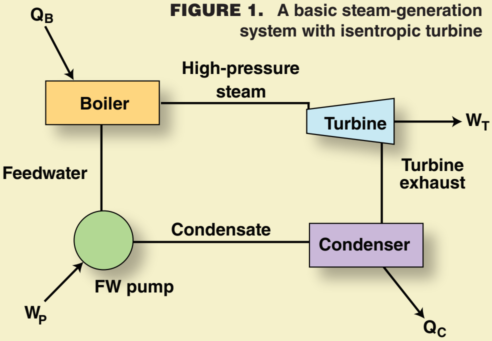
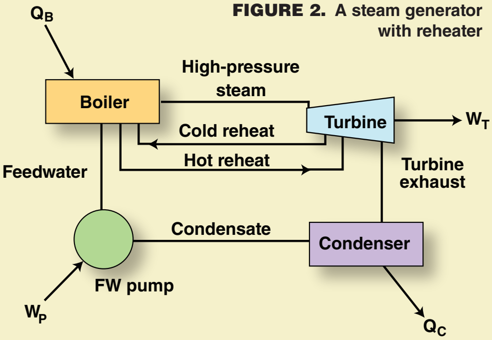



**FIGURE 2.** A steam generator with reheater




## Superheating

The temperature to which the steam is raised above saturation represents the degree of superheat. Almost 1,000 Btu are required to convert a pound of water into a pound of steam. Only about one-third of the energy contained within superheated steam is available for work in conventional steam turbines. However, research into more temperature-resistant superheater and reheater tube materials continues. Modern supercritical boilers achieve almost 45% in overall efficiency, while combined cycle units can reach nearly 60% overall efficiency, where electrical production is split between the combustion and steam turbines.

## Reheating

In an ideal steam-turbine engine, superheat energy would be completely consumed at the last low-pressure turbine blades. A delicate balance must be struck in order to extract all of the available energy from the steam to power the turbine, but simultaneously prevent excessive condensation on the low-pressure blades. Water droplets condensing on the blades are a challenge to be addressed and can cause significant damage. Therefore, steam reheating and operating at elevated pressures become important to efficient processes. Drawing from the previous example, when the steam pressure is raised to 2,000 psia, the turbine work output and overall efficiency rises, but the steam quality is only around 77%, which means that 23% of the fluid exits as condensed water droplets. This level of moisture can damage low-pressure turbine blades. A rule of thumb suggests that 10% moisture at the turbine exhaust should be an upper limit.

Reheating the steam, as pictured in Figure 2, can help alleviate this difficulty. Calculations show that the reheating process improves the turbine exhaust steam quality from 77 to 90%. Calculation of the work output, boiler heat input and efficiency of this case becomes slightly more complicated because work is done by two separate steam feeds to the turbine, and heat is added to two separate steam systems in the boiler. Reheating considerably increases work output as compared to the non-reheated system, but also raises the fuel requirements to the boiler. In a well-designed reheat system, the moisture in the turbine exhaust system is reduced to low levels, and the increased fuel requirement is more than offset by increased work output and better steam quality.

## References

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2. Heat Exchange Institute, Tech. Sheet no.113, February 2005.

Editor's note: This edition of "Facts at your Fingertips" was adapted from the article in Ref. 1.


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## People

### WHO'S WHO


Cronin


Ivers


Kolstad


Saunders


Prentice

**Intelligrated** (Cincinnati, Ohio), a provider of automated material-handling solutions, promotes *Greg Cronin* to executive vice president.

*René Umlauft* becomes CEO of turbomachinery manufacturer **MAN Diesel and Turbo** (Augsburg, Germany).

*Terrance Ivers* becomes CEO of the Compression and Solutions Business Unit of **Siemens Energy Sector, Oil and Gas Div.** (Erlangen, Germany).

*Jeffrey Kolstad* joins **Avantium** (Amsterdam, the Netherlands) as chief scientist, to pursue the development of advanced bioplastics based on the company's YXY technology platform.

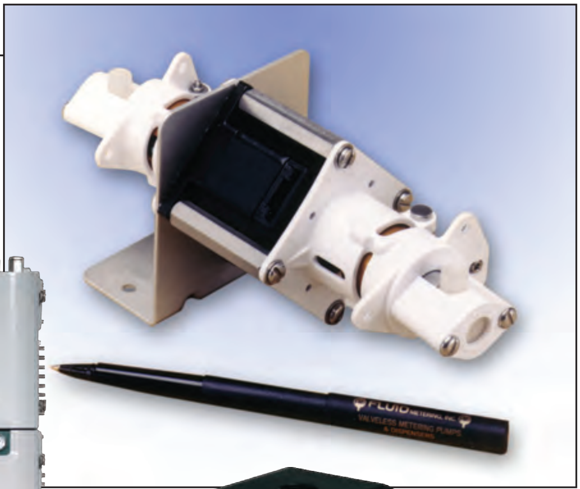
**Moore Industries International** (North Hills, Calif.), manufacturer of electronic measurement and interface instruments, promotes *Scott Saunders* to COO (he maintains his current role as vice president of sales and marketing), and *Gary Prentice* to national sales director.

**Mississippi Lime Co.** (St. Louis, Mo.) names *William (Bill) Ayers* president and COO. *Mike DeCola* will continue to serve as CEO.

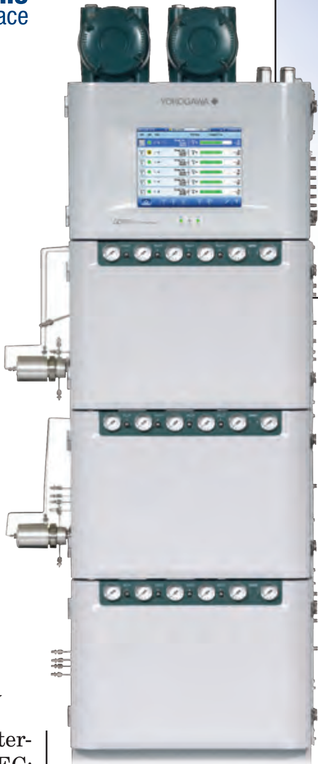
**Dupré Logistics LLC** (Lafayette, La.) has announced three appointments: *Scott Allen* becomes director of fleet assets and maintenance, *Earnie Seibert* becomes vice president of sales and marketing, and *James Winton* becomes director of Operations for the Energy Group. ■

*Suzanne Shelley*

Fluid Metering



The 2011 CHEMSHOW
Processing Solutions for a Changing Marketplace



Yokogawa

Flotronic Pumps

The 2011 Chem Show (www.chemshow.com) will take place in New York on November 1–3 at the Jacob Javits Convention Center. Among the leading chemical process industries (CPI) events in North America, the 54th biennial Chem Show has been an important information resource for CPI professionals since 1915. The Chem Show is a hands-on, interactive event that showcases a wide spectrum of emerging technologies and focuses on such key processing areas as:

- Process control and automation solutions
- Optimizing process efficiency
- Water/wastewater treatment
- Emerging technologies
- Saving energy and sustainability

Produced and managed by the International Exposition Company (IEC; Westport, Conn.), the Chem Show is expected to draw over 200 exhibitors and 2,500 attendees. For the first time, the educational program of the event will be hosted and coordinated by the American Institute of Chemical Engineers (AIChE; New York; www.aiche.org). The multifaceted, three-day program will address a wide range of critical industry topics ranging from new developments, such as nanotechnology, to technical sessions on powder and bulk processing. This event is known as "AIChE's Northeast Regional Conference at the Chem Show." The educational program includes technology tutorials, a conference on energy, safety and consulting, as well as a special track on nanotechnology.

This year's event is accompanied by a suite of online tools designed to help CPI professionals maximize their experience. Visitors to the Chem Show website can search for exhibitors by name or alphabetically, search products by category and company name, access an interactive floorplan and create a customized show planner. The 2011 Chem Show will also feature a mobile version of the show's website to allow smart phone users to access the website's features.

## Products and services

The following descriptions represent a sampling of the products and services expected to be on display at the Chem Show event.

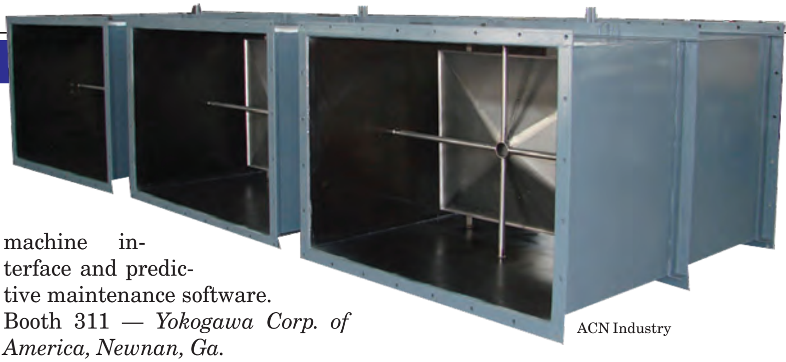
### These pumps deliver precision fluid control

The STH and STQ Ratio:Matic Duplex pumps (photo) feature this company's valveless piston pump technology, and are ideal for precision mixing, diluting and proportional metering for OEM (original equipment manufacturer) analytical, industrial or medical instrumentation. The displacement of each pump head is independently adjustable, and a variety of pump head sizes can be used in combinations to achieve dispensing ratios from 1:1 up to 500:1. Each pump head is calibrated at the factory and locked in place, so it will not require recalibration in the field, even after millions of cycles, the company says. The unique pump design utilizes only one moving part — a rotating and reciprocating ceramic piston that performs both pumps and valving functions without valves. Booth 213 — *Fluid Metering Inc., Syosset, N.Y.*
**www.fmipump.com**

### Handle low-flowrate aggressive chemicals with this pump

The Minichem pump (photo) is a new air-operated, double-diaphragm (AODD) pump designed for aggressive chemicals and hazardous materials at flowrates of up to 100 L/min through 0.5- and 1.0-in. connections with the absence of any housing and separate manifolds. The affordable Minichem has no manifold seals, and is machined from a single, solid block of PTFE (polytetrafluoroethylene). The construction minimizes potential leak paths. The Minichem pump features this company's "one-nut" assembly concept, which makes stripping and rebuilding the pump straightforward

*Note*: For more information, circle the 3-digit number on p. 78, or use the website designation.



ACN Industry

and allows easy diaphragm replacement. Booth 339 — *Flotronic Pumps Ltd., Bolney, U.K.*
**www.flotronicpumps.co.uk**

**A process GC that makes parallel chromatography practical**

The GC8000 process gas chromatograph (GC) (photo, p. 24D-1) introduces the GC Module concept, which sets up virtual GCs within a single analyzer and makes parallel chromatography practical. All chromatograph settings, displays and data are truly segregated for easy understanding and maintenance. Built-in graphical overview screens show each of the individual GC modules. Features of the instrument include the ability to customize the analytical oven configuration for demanding applications, and thermal conductivity detector capable of measuring to the low parts per million range. The GC8000 also features an intuitive touch-screen human-machine interface and predictive maintenance software. Booth 311 — *Yokogawa Corp. of America, Newnan, Ga.*
**www.yokogawa.com/us**

**This gas flowmeter works for large or jacketed ducts**

Designed for monitoring combustion air or fluegases, the Rectangular Conical flowmeter (photo) from this company is available for large-sized, tapered or jacketed ducts. The unit offers accuracies to 0.5% and repeatabilities to 0.1%, the company says. Features of the flowmeter include an anti-fouling and anti-clogging design that is suitable for dirty gases and slow flows. It also has no moving parts, which minimizes maintenance and lengthens service life. It works best with combustion air, fluegas, stack gas, coke-oven gas, exhaust air, biogas and powdered fuel gas in several industries. Booth 608 — *ACN Industry Inc., Shanghai, China*
**www.acn-industry.com**

**This thin-film processor requires a smaller footprint**

The Rototherm V is a mechanically aided, continuous vertical processor (photo, p. 32D-3) designed for concentration, evaporation and stripping applications in the food, oleochemical, pharmaceutical and polymer industries. The unit's vertical orientation offers the potential of a smaller footprint. The Rototherm V handles high-

Artisan Industries


KNF Neuberger

viscosity, heat-sensitive and solids-containing materials, which the company says can be a limitation of conventional evaporators. Booth 228 — *Artisan Industries Inc., Waltham, Mass.*
**www.artisanind.com**

**This pump has a redundant diaphragm design**

Process pumps from this company (photo) are designed to provide superior levels of gas tightness and leakage protection for transferring hazardous, toxic or rare gases. They have a redundant diaphragm design that offers an effective safeguard against escaping gas in the event that the primary diaphragm becomes damaged. The paired diaphragms enclose a pressure- and vacuum-tight safety space that can be monitored for pressure changes. The pumps can be specified for emissions sampling and monitoring, analytical instrumentation and process engineering applications, and can achieve leak rates as low as $6 \times 10^{-6}$ mbar/s. Booth 736 — *KNF Neuberger Inc., Trenton, N.J.*
**www.knfprocess.com**

**Handle viscous and corrosive fluids with this flowmeter**

Model IOG flowmeters (photo, p. 32D- are stainless-steel, oval-gear meters that are designed to withstand extreme conditions, including use with highly corrosive or viscous fluids. The IOG is ideal for chemical, cosmetic, acid, water mix and fertilizer applications, the company says. The initial

product offering will include 0.5-, 0.75- and 1.0-in. sizes, and is available with flanges or inline national pipe thread or British straight pipe threads. With a simple design, the device requires little maintenance, and provides high accuracy in low-flow environments. The industrial oval-gear meters operate up to 800 psi and can achieve accuracies of ±0.5%. Booth 415 — *Badger Meter, Milwaukee, Wisc.*
**www.badgermeter.com**

Badger Meter

### A belt filter with a novel design

The RB-SV horizontal vacuum belt filter has the vacuum box placed on the side of the rubber belt, rather than directly underneath the belt and along the center line of the filter. Locating the vacuum under the belt, as is traditionally done, is good for processing, but has significant limitations in maintenance and cleaning. The relocation enables the operator to inspect the equipment without having to stop or physically enter the unit. This ability is a tremendous advantage in applications where frequent cleaning of the vacuum box is necessary because of crystallization, such as potash and phosphoric-acid processing. The side-located vacuum box has itself been engineered to eliminate corners and dead spots to minimize the locations where scaling and crystallization occur. Booth 650 — *Outotec Oyj, Espoo, Finland*
**www.outotec.com**

### An effective solution for removing solid particles from sludge

The Auto-Vac is a rotary vacuum drum precoat filter that effectively removes solid particles from sludge, producing dewatered dry waste. Typically, this waste can be disposed of at a local landfill without further drying. Auto-Vac is self-cleaning with every revolution, which prevents blinding or clogging, and provides rapid filtration and extremely high filtrate clarity. The Auto-Vac filtering system is skid mounted, pre-piped and pre-wired for easy installation. It is offered both with semi-automatic and automatic modes of operation. This design works with virtually any industrial waste. It is available with 16 filter sizes. Booth 420 — *Alar Engineering Corp., Mokena, Ill.*
**www.alar.com**

### Compact flowmeters for low flowrates

The mini Cori-Flow Series is a group of compact and cost-effective Coriolis mass flowmeters (photo, p. 32D-5) that can also control flow at very low flowrates (from 400 mg/h to 30 kg/h). The unique design of the miniature Coriolis sensor features quick response time and high accuracy despite changing operating conditions, including pressure, temperature, density, conductivity and viscosity. The device is suitable for both liquid and gas flow applications, and is capable of bi-directional measurement. Mini Cori-Flow offers functions such as alarms, measurement of total fluid consumption, and batch dosing. Typical applications include research laboratories, pilot plant, semiconductor and fuel cell processing, pharmaceutical and food industries, and microreactors. Booth 602 — *Bronkhorst USA Inc., Bethlehem, Pa.*
**www.bronkhorstusa.com**

### These vacuum pumps deliver performance in harsh processes

CXS dry-vacuum pump products are designed for harsh chemical, Bronkhorst


petrochemical and pharmaceutical processes. The pumps feature an advanced tapered-screw technology that provides fast pumpdown to vacuum pressures of $10^{-3}$ mbar. Simple to install and easy to maintain, the CXS pumps are robust and reliable in harsh pumping environments. They are also designed to be explosion-proof. The pumps are suitable for vacuum applications in distillation, drying, evaporation, reactor service, house vacuum, solvent recovery, crystallization and filtration, the company says. Booth 808 — *Edwards Ltd., Crawley, U.K.*
**www.edwardsvacuum.com**

**These pumps are ideal for removing product from vessels**

The GX Series sliding vane pumps have been designed for versatility, handling a wide range of noncorrosive solvents and industrial liquids. The cast-iron GX pumps are ideal for removing product from vessels, storage tanks or transport tankers. Equipped with integral head-mounted gear-reduction drives with oil-lubricated, hardened helical gears, the product is available in four different models with capacities from 40 to 528 L/min. The GX pumps have a self-priming design with high suction-lift capabilities. Booth 540 — *Blackmer Co., Grand Rapids, Mich.*
**www.blackmer.com**

**Perform heating and chilling from a single unit**

The Full Range unit (photo, p. 32D-6) integrates this company's circulating-water temperature control system with its portable chiller to provide heating and cooling from a single package. The system is ideal for applications that require both heating and cooling, including jacketed vessels, reactors, multiple-zone processes and others. Systems are available up to 96 kW, 120 gal/min and 2- to 40-ton chilling capacities. Custom options include NEMA 4 and NEMA 4X enclosures, cleanroom designs, washdown capabilities and stainless-steel cabinetry. Booth 621 — *Mokon Inc., Buffalo, N.Y.*
**www.mokon.com**

Mokon


**This belt filter has a large area**

With a 3.50-m-wide belt, this company's belt filter offers 73.5 $m^2$ of filter area. The belt filter is capable of handling a range of filtration applications, as well as washing and drying of high-value product in an alkaline slurry. The unit also features a candle filter system to recover fines and recombine them into the process, thus maximizing product recovery. Booth 3325 — *BHS Filtration Inc., Charlotte, N.C.*
**www.bhsfiltration.com**

**Pinpoint overpressure conditions with this device**

The Relief Device Manager (RDM) is designed to help plant owners and operators identify the precise operating conditions of an overpressure event and properly diagnose problems. Pressure relief devices activate instantaneously, creating challenges for plant personnel to accurately draw conclusions about the relationship between process conditions and pressure relief devices, such as rupture disks, pressure relief valves, explosion vents and others. The lack of definitive information allows the risk of repeated incidents and compromised safety. The Microsoft Windows-based RDM system allows continuous monitoring of overpressure relief devices. RDM provides alarms, warnings and performance history if events compromise the integrity of pressure safety systems, the company says. Booth 1003 — *BS&B Safety Systems LLC, Tulsa, Okla.*
**www.bsbsystems.com**



**A steel-belt system that self-adjusts**

The Bernmatic steel-belt tracking system is position-adjustment software that recognizes belt tracking trends, and causes the belt control drum to slew in proportion to the deviation of the steel belt. The control system guarantees perfect tracking, the company says. The Bernmatic system can continuously control belt tension, as well as the position of each spindle or cylinder, which prevents excessive stress to the belt edge. The company also offers a wide variety of other ancillary devices for steel belts in the chemical industry. Booth 827 — *Berndorf Belt Technology USA, Elgin, Ill.*
**www.berndorf-usa.com**

**Protect personnel and equipment with this explosion vent**

The new MV-RD explosion vent is offered for protecting personnel and equipment during deflagrations in high-cycling and high-vacuum applications. The vent provides extended in-service life, lower burst pressure in smaller sizes and an industry-first, two-year warranty. The MV-RD is designed for high-cycling applications, such as in dust collectors and bag houses that experience vacuum pressures up to 12 psig. The vent mounts on enclosures where dust explosions may occur, and will activate to safely relieve pressure in the event of a deflagration, thereby preventing a large explosion. The vent can also be used on bulk storage units and in ductwork applications requiring a square explosion vent. Un-

Fike


like other domed vents, the MV-RD can operate in temperatures up to 450°F. Booth 3301 — *Oseco, Broken Arrow, Okla.*
**www.oseco.com**

**Wide-ranging enhancements to this design software**
ChemCAD, an integrated suite of chemical process engineering software, features continuous improvements that evolve as industry changes. In the latest version of the software, engineers will find a licensing tool that expands the capabilities for computer licensing, as well as improved dynamic column performance and the capability for simultaneous heat- and mass-transfer models in distillation columns. The enhancements also include an improved user-defined component database that enables users to specify electrolyte density, viscosity, diffusivity, Henry's Law constants and more. The newest ChemCAD version also features a new operating mode that can help speed calculations for complex simulations. Booth 3306 — *Chemstations Inc., Houston*
**www.chemstations.com**

**Rupture discs made without hard-score tooling**
This company has developed a technology to manufacture rupture discs (photo) without using hard-score tooling. The process results in rupture discs free of stress marks and tool marks, allowing extremely high operating ratios, the company says. All rupture discs are compliant with relevant global codes and are designed to meet or exceed industry requirements for performance and reliability. Booth 421 — *Fike Corp., Blue Springs, Mo.*
**www.fike.com**

**An onsite hydrogen generator with high efficiency**
This company's Prism Hydrogen Generator offers cost-effective onsite hydrogen production. The Prism's proprietary design allows the lowest consumption of natural gas and the highest turndown, the company says. The Prism is configured to meet hydrogen production requirements from 2,000 up to more than 10,000 $ft^3/h$. The fully skidded, modular design of the units facilitates low-cost installation and maintenance. Prisms are suitable for generating high-purity hydrogen in applications in the chemical process, metals treatment, steel, glass, photovoltaic, food, power generation and hydrogen fueling industries. The company will also feature a liquid-hydrogen supply system. Booth 210 — *Air Products Inc., Allentown, Pa.*
**www.airproducts.com** ■

*Scott Jenkins*

# OCTOBER New Products

Omega Engineering


ACS Valves

Moore Industries International


**This rotary feeder valve is designed for abrasive materials**

Designed specifically for rugged applications and processing of harsh and abrasive materials, the CI Series of rotary feeder valves (photo) provides bulk-material processing operations with continuous performance, reduced maintenance and optimal energy efficiency. The valve housings are cast to ensure strength, and the outboard bearing design of the CI Series extends bearing life and protects the bearings in high-temperature (up to 750°F) applications. The CI Series design can easily manage applications with pressure differentials of up to 15 psig, and minimizes pressure loss throughout the system. The CI Series valves are available in cast iron or stainless steel (304 and 316), and available with a variable frequency drive to modulate drive speed and reduce power requirements. — *ACS Valves Inc., Caledonia, Ont., Canada*
**www.acsvalves.com**

**View this pressure-gage display from afar**

The DPG409 Series high-accuracy digital pressure gages (photo) feature a large backlit display that allows users to read the digits from 35 feet away. The rugged stainless-steel enclosure is designed specifically for washdown, sanitary and marine applications. The DPG 409 Series can monitor pressure from vacuum to 5,000 psi, and all units include setup software. Connected via a USB connection, the software helps to speed installation and calibration. The wireless transmitter option sends readings to remote locations and allows for PC-based chart recording and data logging. — *Omega Engineering Corp., Stamford, Conn.*
**www.omega.com**

**This vacuum filter has a swing-out base and side discharge**

The Simplefilter consists of a heated insulated vessel, with a filtration media that is attached to a heated swing-out base and a side-discharge hatch. The design makes drying efficient and removal of the product less complicated. High containment discharge is also available for highly active or cytotoxic products through a nitrogen-purged glovebag. The mobile unit is designed for chemical and pharmaceutical applications, such as carbon filtration, catalyst recovery, pre-filtering for microfiltration, active pharmaceutical ingredients and intermediate filtration. — *Powder Systems Ltd., Liverpool, U.K.*
**www.powdersystems.com**

**These emergency lights have battery options**

The HLEL Series of emergency lighting fixtures offers a fiberglass-reinforced polyester housing that is suitable for use in indoor hazardous environments, such as oil and gas production, industrial manufacturing, wastewater treatment plants or other interior spaces where hazardous gases and dusts are present. The emergency lights are available with either tungsten or halogen PAR (parabolic aluminized reflector) 36 lamp heads and with multiple Wattages. They also are available with lead- and nickel-cadmium battery options. — *Rig-A-Lite Inc., Houston*
**www.rigalite.com**

**Increase capacity with these membrane filtration modules**

The latest version of this company's Puron membrane bioreactor (MBR) filtration modules allows a possible 25% increase in capacity over the previous version. The Puron PSH1800 offers superior solids management and reduced energy costs, the company says, thanks to a 10% lower aeration requirement and a 10% greater surface area than competitive products. The Puron PSH1800 features central aeration and a single header design that makes the unit one of the highest-packing, smallest-footprint devices available (1,800 $m^2$ of filter area in a 1.75 x 2.42 m footprint. — *Koch Membrane Systems, Wilmington, Mass.*
**www.kochmembrane.com**

**Use this signal isolator in hazardous areas**

The HIX HART signal isolator (photo) recently received certification from third-party testing organization CSA International for use in general locations, and in Class I, Division 2 (non-incendive) industrial areas. The two-wire HIX provides superior loop isolation while allowing the HART signal to "pass through" uninterrupted, the company says. The HIX provides solutions from three common and costly problems that plague many of today's smart HART loops: it protects I/O cards from surges and spikes; it provides area isolation to allow loops to continue working during system maintenance downtime; and it provides a safe method of sharing a HART signal. The CSA approval allows the HIX to be used in hazardous conditions where flammable gas or vapors are present in the atmosphere. — *Moore Industries International Inc., North Hills, Calif.*
**www.miinet.com** ■



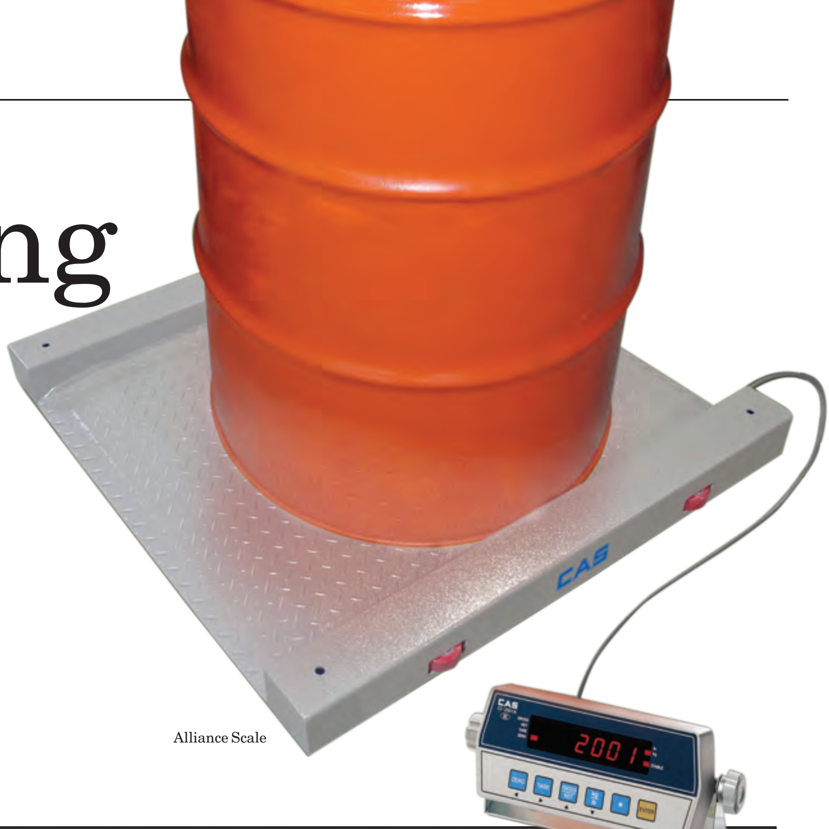
*Note*: For more information, circle the 3-digit number on p. 78, or use the website designation.

# FOCUS ON

# Weighing

### A portable platform scale for containers

The new R-Series drum scale (photo) is a portable platform scale designed for weighing drums, barrels, containers, skids and pallets. The scale includes access ramps on two sides, and side rails to keep items on board. The unit has built-in handles and two rubber wheels to allow users to easily move the scale around. The low-profile scale has a six-digit digital indicator, an anti-slip platform and a 1,000-lb capacity. The unit is constructed of steel with a powder-coat finish, and measures 42.75 in. wide, by 39.5 in. deep, by 3.5 in. high. — *Alliance Scale Inc., Canton, Mass.*
**www.alliancescale.com**




Alliance Scale

### This system includes solids-weighing components

An automated plant-wide weigh-batching system from this company (photo) can simultaneously weigh up to seven major ingredients received in 50-lb sacks, and then convey the weighed batches to a downstream blender. The weigh-batching system includes two loss-of-weight bulk bag dischargers, two loss-of-weight bag dump stations, and a check-weighing hopper, among other components. The system's filter receiver discharges weighed material into a high-capacity blender that is mounted on load cells, which can confirm final batch weight. — *Flexicon Corp., Bethlehem, Pa.*
**www.flexicon.com**

Flexicon

### Four mounting options are available for these weighing systems

This company's G4 family of multi-channel weight and force indicators is available with four mounting options – DIN rail, panel, desktop and harsh environment. The G4 instruments offer high speed and performance for industrial applications, such as process weighing and control, force measurement, web tension measurement, automation, force vector calculations, high-speed blending systems and more. The modular nature of the units provide users with a highly flexible, upgradeable, single-instrument system that is capable of weighing up to eight different vessels. Recently, the G4 family received approval from FM Approvals LLC. — *Vishay Precision Group, VPG Process Weighing Div., Malvern, Pa.*
**www.weighingsolutions.com**

### Keep food production safe with these scales

The ICS4_9 and the ICS6_9 are portable weighing scales (photo, p. 36) specifically designed for use in food processing applications. Users can track and trace samples, and configure the product for easy integration into an existing process. The stainless-steel construction coupled with double-sealed display termi-

*Note*: For more information, circle the 3-digit number on p. 78, or use the website designation.

Mettler-Toledo

nals make the units durable enough for high-pressure washdowns. Also, the scales are more user-friendly, allowing a broader array of manual partitioning and checkweighing processes. The company also recently introduced the PFA569 lift, a stainless-steel floor scale with an easy-to-lift platform for simplified washdown in hygienic applications. — *Mettler-Toledo Inc., Columbus, Ohio*
**www.mt.com**



**These weighing systems come pre-programmed**

Each 920i FlexWeigh System model is a standard design in its own right, and comes pre-engineered and pre-programmed for a variety of weighing applications. The 920i FlexWeigh is also customizable, allowing users to integrate the systems into a particular operation. The unit is built for long-lasting dependability, with stainless-steel NEMA-4X enclosures and customizable operation switches. The 920i FlexWeigh combines advantages on the user interface and control panel from previous products. — *Rice Lake Weighing Systems, Rice Lake, Wisc.*
**www.ricelake.com**

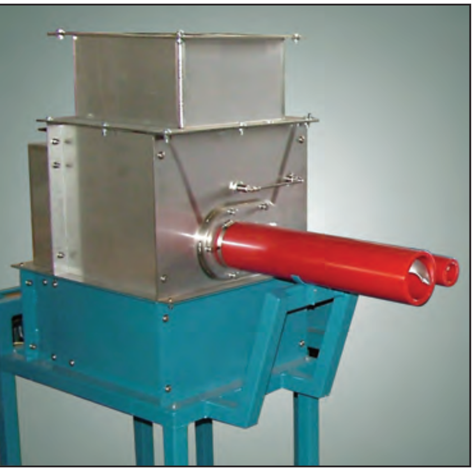
**Weigh and pack solids with this system**

The GWT grid-top vibratory weigh-scale packers can fill containers with bulk solids, weigh them and convey them before sending them on to the next stage. The GWT packer weighs the container throughout the entire process of compaction and filling. GWT models are available in a range of deck configurations, with either rotary-electric or air-cushioned-piston vibrator drives. The digital scales incorporate set points to control the start and stop of the fill device and the vibration sequence. — *Cleveland Vibrator Co., Cleveland, Ohio*
**www.clevelandvibrator.com**

**This feeder is for precise weighing applications**

The Model TSF twin-screw feeder (photo, p. 37) is designed for precise weighing and batching applications.

Metso Mineral industries

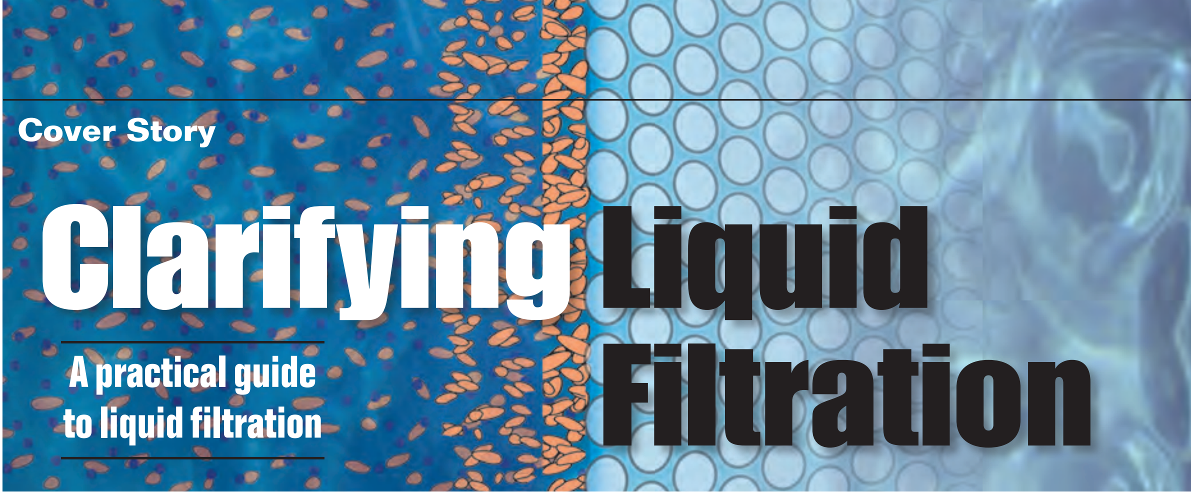


Cardinal Scale Manufacturing


It is ideal for batching to weigh-hoppers, as well as loss-in-weight scale-monitored flow and loss-in-weight batch applications with scales. The feeder has a twin-screw feeding system to allow for a compact design that is suitable for limited space areas. — *Metso Mineral Industries Inc., Brunswick, Ohio*
**www.metso.com**

**Use this weigher in extreme applications**
The 190 Storm digital weight indicator (photo) is designed for extreme-use applications in the chemical industry. Its polycarbonate enclosure can withstand washdowns with temperatures up to 176°F and pressures up to 1,450 psi. The Storm 190 features a bright, vivid display that changes color automatically as the pre-assigned target weight is reached. The unit shows an amber color to indicate underweight, green to indicate accepted weights and a bright red color when the weight exceeds the upper limit. The combination of the rugged watertight polycarbonate enclosure and capacitive touch keys allow total protection from sharp objects, impacts and harsh environments. The Storm 190 scale is ideal for applications in the chemical industry, as well as food, pharmaceuticals and others. — *Cardinal Scale Manufacturing Co., Webb City, Mo.*
**www.cardinalscale.com** ■

*Scott Jenkins*



Cover Story

# Clarifying Liquid Filtration

## A practical guide to liquid filtration

**José M. Sentmanat**
Liquid Filtration Specialists, LLC

There are various reasons that make filtering necessary in processes. The raw materials might have impurities that require removal at the start of the process. After the initial mixing to produce the process slurry, the mother liquor could have solids that need a separation process. Unwanted solids could also form by a chemical reaction during the production of the process liquid. The nature of the solid impurities will ultimately determine the type of equipment needed for the separation process.

Sometimes, a preliminary crude separation is done by decantation, clarification, settling, coalescing or centrifuging. For some processes, a preliminary coarse prefiltration with a basket filter or a strainer is used to remove the bulk of large crystalline solids, using a relatively open filtering medium. After this coarse separation (if needed), the actual fine liquid-filtration process is performed to produce the final, clear filtrate product.

This article offers recommendations and guidelines to apply in the selection, operation and troubleshooting of liquid filters. The first step in deciding which filtration method to use in a process begins with laboratory testing.

## LABORATORY TESTING

The importance of laboratory testing cannot be over stressed. The laboratory is where you will determine the nature and properties of the solids, and the ease or difficulty of the filtration process. Also, knowing the amount of solids and the particle size are factors necessary in specifying the filter media, filter aids, filter area, cake space needed and cake discharge technique. The experimental data gathered in the laboratory are also necessary for the design of the filtration system needed for production.

### Preliminary testing

First, you need to produce a realistic and comparative test sample for the actual process fluid. Once this sample is available, run it through a small laboratory centrifuge to determine the amount of suspended solids. The separated solids should then be examined visually because the nature of these solids will greatly affect the filtration process. Solids that are crystalline can be relatively easy to filter, whereas amorphous, slimy or gelatinous solids are more difficult to separate, requiring more complex techniques.

In addition to the visual inspection, particle-size analysis of the suspended solids is always recommended to determine the percentage of solids and the particle-size distribution you are dealing with in the process.

### Laboratory procedures

Figure 1 shows three different laboratory filtration setups. Testing stations such as these are used to establish the filterability of the product in question and to calculate the filter area and the thickness and weight of the filter cake. Filter testing also establishes the process filtering pressure and the required air pressure for blowing down the filter to remove all liquid from the filter tank. The test data will help determine the size and recommendation for the filter type.

The filter area of the laboratory filter is established prior to testing. The laboratory filter must have pressure-measuring devices to measure the feed and the discharge pressures. A small pump is used to feed the process liquid into the filter. In the absence of a pump, air or nitrogen is used to push the liquid through the filter.

A representative sample of the process liquid is prepared and properly mixed to keep the solids in suspension. The feed solution is prepared in a container that allows measurement of the volume of the test batch for filtration. The filtered solution (filtrate) is collected in a receptacle that allows measurement of the filtrate volume after a measured filtration time. A stop watch or timer is used to track the time required for the filtration process from start to finish.

For constant flow operation, the test solution is fed into the filter, and the discharge pressure of the pump (or the air or gas pressure) is increased gradually in order to maintain a constant flow. For constant pressure testing, the process solution is fed into the filter at a constant pressure. In this case, the flow through the filter will gradually decrease as the filter cake is built up and resistance to flow increases.

The test data are then used in the following formulas to calculate filter sizing requirements to meet the process flowrate, batch throughput and the solids removed in the filter cake:

$$\text{Throughput} = V/A \quad (1)$$

$$\text{Flowrate} = (V/\Delta t)/A \quad (2)$$

$$\text{Cake thickness} = W_s/\rho_s A \quad (3)$$

Where:
$V$ = total volume filtered, gal
$A$ = total filtration area, ft$^2$
$\Delta t$ = total time to filter, min
$W_s$ = total weight of solids filtered, lb
$\rho_s$ = density of wet cake, lb/ft$^3$

If laboratory testing is not feasible at your plant, filter equipment companies, filter aid suppliers and consultants are available to assist you with test work.

Imerys Filtration Minerals USA

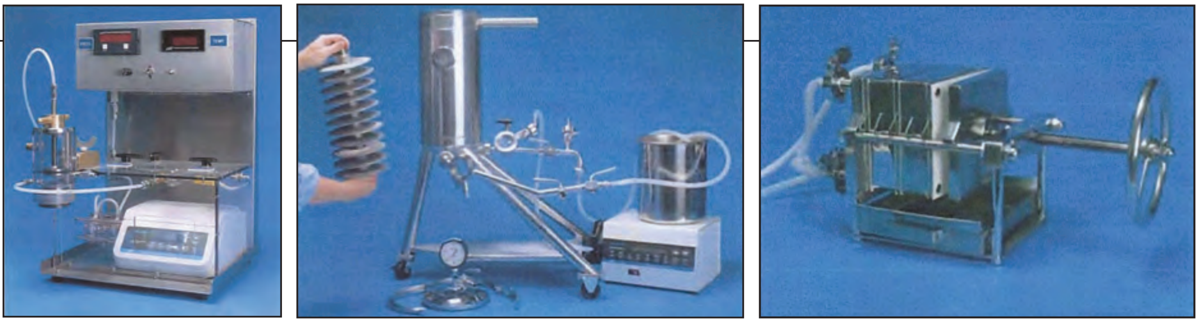


**FIGURE 1.** Laboratory testing is crucial for the design of a filtration system. Shown here are a Walton test filter station (left), a horizontal-leaf pressure filter test stand with multiple plates (middle), and a plate-and-frame test stand with two plates (right)

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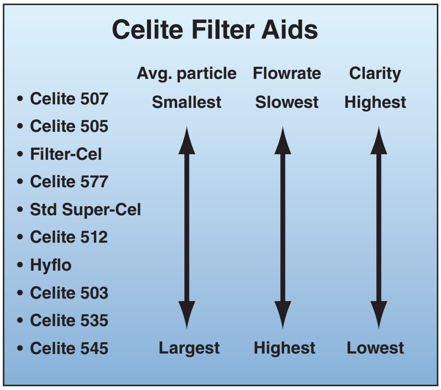



**FIGURE 2.** Various grades of calcined diatomaceous earth are available

## Filter aids

Laboratory tests will help determine if precoating is necessary. Precoating, as the name implies, is a technique in which the filter media is first coated with a filter aid. These filter aids are used to do the following:

- Protect the filter media from plugging or blinding with suspended solids
- Obtain the desired initial clarity
- Facilitate the filter cake release during the cleaning of the filter

Filter aids are also used as a body feed to help keep the filter cake open for good cycle times. The most common filter aids are as follows:

***Diatomaceous earth.*** This material is made from silica fossils of unicellular organisms that come from salt water or fresh water deposits. Various grades of diatomaceous earth are available, depending on the degree of fineness required. Some of the finest grades are flux calcined (Figure 2).

***Perlite.*** Perlite is made of expanded ground volcanic-lava rock. It, too, is available in various grades depending on the degree of fineness needed.

***Cellulose.*** Expanded cellulose material is also graded by fineness.

***Blends.*** Blends of diatomaceous earths with either coarse fibers or graded fibers of cellulose can be used to aid filtration.

***Carbon-based aids.*** Carbonaceous-type filter aids are normally used when the chemistry of the process liquid may react with the silica in diatomaceous earth or perlite products.

***Other materials.*** Calcium carbonate or similar solids can serve as a filter aid due to their crystalline nature, and may already be present in the process liquid.

The selection of the best filter-aid material for the process feed should include consultation with a representative from the manufacturers of filter aids. More detailed information on filter aid types can also be found on many suppliers' Websites.

## Filter media

Laboratory tests also help determine the type of filter media needed for placing over the filter elements. The filter elements consist of a porous or coarsely open member that supports the filter media, which is the base or septum for holding the filter cake. The filter media is the separation point for the flow of clean filtrate into the process.

Types of filter media available are the following:

***Paper.*** Paper media are disposable filter sheets made of either cellulose-type filter paper or non-woven type synthetics.

***Pads.*** Filter pads are disposable and thick pads of cellulose fibers or a blend of cellulose fibers and diatomaceous earth, which actually serve as a precoat and do not require an additional filter aid precoat to perform the filtration.

***Textiles.*** Cloths made of natural cotton, wool or synthetic fibers are used. Cotton and wool cloths have limited use due to their resistance to chemicals. Synthetic cloths have better chemical resistance, depending on the nature of the fibers. Synthetic cloths are made of polyolefins, such as polyethylene or polypropylene, polyesters, nylons, Nomex, fluorocarbons (Teflon, Kynar), Saran or a variety of high chemical and temperature resistant man-made fibers.

***Felts.*** Felts of natural cotton, wool or synthetic fibers are available in various materials and porosities like textile cloths. The most widely used are polypropylene and polyester felts.

***Metallic wire mesh.*** Made in various wire weaves for different uses and retentions, wire meshes are available in various metals according to the chemical resistance required, including 304 stainless steel (SS), 316-SS, 316-LSS, Monel, nickel, Inconel, Hastelloys, and other chemical- and temperature-resistant metals.

***Porous or sintered metals.*** Multilayered, fused-wire mesh weaves and metal felts are also available.

Filter paper or pads are typically used only once, whereas cloth, wire mesh, felts and sintered metals or multilayer wire mesh are more permanent or reusable filter media that do not require replacement after each filter cycle.

# FILTER SYSTEMS

In choosing the filter, selection depends on several considerations. What is the duty of the filter? What is the sizing requirement to carry the process flowrate and contain the solids removed? What filter area ($ft^2$) and cake capacity ($ft^3$) is needed? Is there a requirement to prefilter? Is the filter for a fine-filtration requirement? Is manual or automatic operation preferred? Is the process batch or continuous operation?

Manually operated filters include basket filters, plate-and-frame filter presses, plate filters and some pressure leaf filters.

Pressure-leaf type filters have features to achieve self-cleaning or automatic cake discharge. These features allow discharge of the filter cake by washing the cake off the filter medium with internal spray headers or by vibrating the cake off with a pneumatic vibrator. Sometimes pressure leaf filters are operated manually with respect to valve operation, but their self-cleaning features remove them from the manual classification. Both horizontal and vertical tank designs are available with hydraulically operated quick-opening closures to speed the opening of the tank for dry cake discharge. Filter media types used are cloth covers, felt covers and wire mesh.

Pressure-leaf type filters handle large volumes of process flow with long filter cycles. Loosely, these filters are referred to as continuous type filters. However, in reality they are not continuous, since they still require a stop in the process for cleaning.

### Basket filters

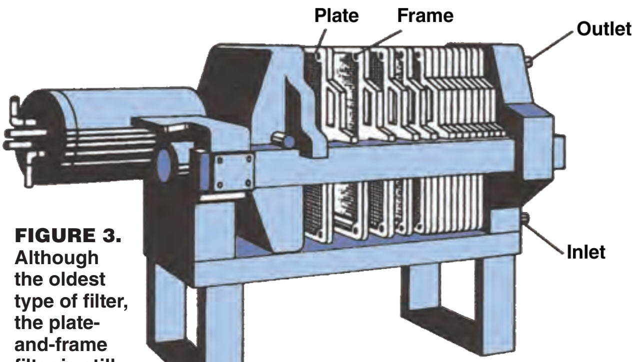
For coarse filtration, the basket or strainer filter type is selected, and consists of a pressure-vessel type housing with a perforated internal member that separates the coarse solids from the process liquid. The internal element is made of perforated metal or is a coarse wire-woven basket. The internal element is removable to clean by simply dumping the solids or by washing them off. These coarse filters remove the larger solids, allowing the finer ones to pass through and are selected based on the process flowrate and the amount of solids to be removed. In some cases the inner element is lined or covered by a woven liner made of either cloth or wire. Cleaning is done by manually removing the basket or strainer or backwashing or flushing in place. These filter types have low maintenance requirements.

### Plate-and-frame filter press

The oldest filter type is the plate-and-frame filter press (Figure 3). In simple language, if you can manage to pump the process slurry into the plates and frames pressed together with compression rods, the slurry will stay there and filter. These filters rely on the type of media used, which is generally the filter sheet or pad for depth filtration not requiring a precoat. The chamber between the filter plates becomes filled by the removed solids until full. There are no concerns about solids settling inside the filter tank or premature filter-cake dropping due to pressure or flow fluctuations.

Once the sludge chamber is full, the filter cake is washed by pushing the wash liquid forward and extracting the mother liquor from the cake prior to drying the cake by blowing air or gas through the cake. These filters are cleaned by simply loosening the compression mechanism and removing the filter sheets or pads with the cake on them and disposing of the cake and the filter media. Media for these filters include filter papers, sheets, pads and cloths. The plate-and-frame filter press is very popular with beverage, winery, and pharmaceutical processors.

A more modern version of filter presses offers advantages like automatic cake removal. Plate shifters allow the remote controlled shifting of the filter plates, so that the cake is popped-off the filter media. Air pressure is applied into an internal bladder that pops off the cake, leaving the filter cloth media in place. Other features are devices to wash the cloth media after the cake is discharged, hydraulic compression of the filter plates, recessed filter plates and molded plates. These newer design filters also offer larger filter areas and cake holding capacities and are preferred for high-solids loading applications in mining, quarries, wastewater and waste-sludge processing plants as well as other similar high-solids applications.



Imerys Filtration Minerals USA

**FIGURE 3. Although the oldest type of filter, the plate-and-frame filter is still widely used**

### Horizontal leaf filters

Plate filters evolved from the original plate-and-frame filter presses to eliminate the concern of leaks or drippings of the process liquid from between the plates and frames. In plate filters, containment of process fluids is achieved by placing the filter plate bundle in a pressure vessel housing (Figure 4). Horizontal filter plates are assembled in a bundle by means of compression rings at the top and bottom and compression center and side tie rods. The plate bundle is placed inside of a vertical pressure vessel. The design varies, depending on the location of the feed port and flow direction across the plates.

In standard horizontal plate filters, the feed liquid fills the tank, then the liquid passes through inlet flow holes in the filter plate rings that separate the filter plates into the sludge chamber. Pressure from the process forces the liquid through the filter medium, supported by a perforated media-support element, down into the clean filtrate chamber and out the center hole of the filter plate into the center outlet opening and out of the filter tank at the center bottom outlet. To filter the remaining unfiltered heel in the tank, some filters have a special bottom-most filter-plate element or scavenger plate in the bundle with a separate outlet to allow filtration of the tank heel contents at the end of the cycle.

Horizontal plate filters are cleaned by removing the filter plate bundle from the tank, disassembling the filter plate bundle and removing the filter medium from each plate with the filter cake. Media used are paper, sheets, pads, felts, cloths and in some instances metal wire-mesh circles.

Figure 4 shows typical horizontal leaf filters with standard forward flow (left) and with reverse flow (right). In the reverse-flow filter design, the feed flows into the bottom-inlet center port of the tank, then into the center feed column formed by the filter plates stack, through holes in the center column at each plate. Pressure forces the feed slurry into the plate chamber and solids are retained on top of the media. Clean feed liquid flows through the filter media, through the filter media support, into the filtrate chamber and out through the side holes in the

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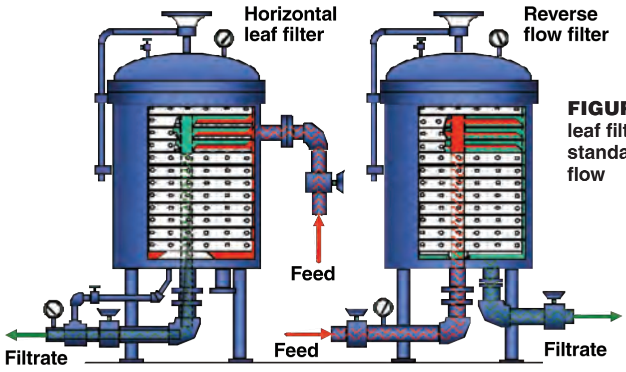


**FIGURE 4.** Horizontal leaf filters operate with standard or reverse flow

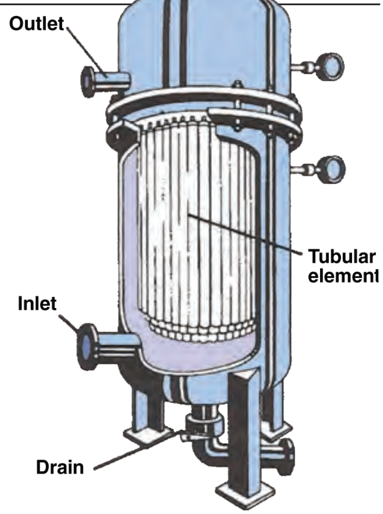


**FIGURE 5.** Tubular filter elements can be cleaned by back washing to discharge the filter cake as a slurry

spacer rings between filter plates. The filtered liquid fills the tank and discharges through the outlet nozzle in the bottom of the tank. Since the unfiltered liquid feeds directly to the filter plate bundle, there is no unfiltered tank heel, and no separate bottom filter plate is needed. The filter tank is only in contact with clean filtered liquid, so the operator does not have to clean the tank as in the standard type. The reverse-flow filter-plate bundle is cleaned and redressed in a similar way to the standard, horizontal plate filter by removing the filter bundle from the tank, dissembling the plates, removing the media and cake and redressing with clean media.

Both types of horizontal plate filters are batch type, manually cleaned and labor intensive filters. The filter cake is always contained on top of the filter media and within the compression rings between the plates for maximum filter-cake stability. If process flow stops for one reason or another, the cake stays in place. To resume filtration, a simple recirculation step is added to reestablish the filter cake, and then production continues without detrimental effects in most cases.

Horizontal plate filters are preferred by small production chemical plants, pharmaceutical, fine chemical, beverage, and other processors who want fine reliable filtration with maximum filter-cake stability and clean-ability of the filter internals.

## Tubular filters

Another self-cleaning type filter is the tubular filter consisting of a pressure vessel and filter elements that are tubular (Figure 5). The tubes are covered with cloth, felt or wire mesh. At the end of the filter cycle, these tubular filters discharge the filter cake by either blowing back to pop the filter cake off the tubular element or backwashing to discharge the filter cake in a slurry form. The limitation of tubular filters is the filter cake capacity.

## Pressure leaf filters

This type of filter can have a vertical or horizontal tank. Horizontal-tank pressure-leaf filters come in two different styles. The stationary tank design (Figure 6) has a leaf bundle that pulls out and away from the tank to expose the leaves for discharge of the filter cake. The stationary leaf-bundle design has a front head that remains stationary with the filter bundle attached, and the tank pulls away to allow discharge of the cake. Additional operating features like rotating plates and internal screw conveyors for cake discharge are offered by some filter manufacturers.

Vertical-tank pressure-leaf filters (Figure 7) with vertical plates have internal spray headers for wet cake discharge or quick-opening bottom-drop doors with pneumatic vibrators for dry cake discharge. They are used in the fine chemicals and food-and-beverage industries.

## Rotary drum filters

Rotary drum filters (Figure 8) are the only truly continuous filter. The filter itself is located on the outer surface of a drum that is under vacuum inside. In a single full rotation of the drum, this system precoats the filter, performs the filtration, washes the filter cake (to recover the mother liquor), and dries and discharges the cake. Filtrate passes through to the center of the drum to where it is recovered. The filtration cycle starts all over again in the next full turn of the drum. Rotary drum systems are used for primary filtration when there are large amounts of solids.

## Belt filters

Another continuous-type filter is the belt filter, which has essentially the same operation as the rotary drum filter, but uses a continuous cloth band instead of a drum. The continuous cloth band travels into the bottom of a trough that is continuously fed the slurry to be filtered. Suction is applied to the cloth, causing the liquid to be filtered as it passes through. The filtered solids remain on the cloth and are dried as the cloth travels out of the slurry, and the filter cake is discharged. At this point the cloth is washed by a spray system to clean the cloth for the next cycle. Continuous belt filters are typically used in the paper and fibers industries.

## Nutsche filters

Some pharmaceutical and fine chemicals processes use a single plate or "Nutsche" type filter. Manual Nutsche filters (Figure 9) consist of a vertical pressure vessel with a single filter plate in the bottom of the tank or a removable basket with a filter plate in the bottom of the basket. Nutsche filters are used to remove and process high bulk-type solids resulting from a reaction where the filter cake is the product.

High bulk solids are porous and allow deep filter-cake beds to form, filtering without filter aids. Processing steps include filling, filtering (either, vacuum or pressure), reslurrying, displacement wash, drying of the filter cake and cake discharge. Cake discharge options include scooping out

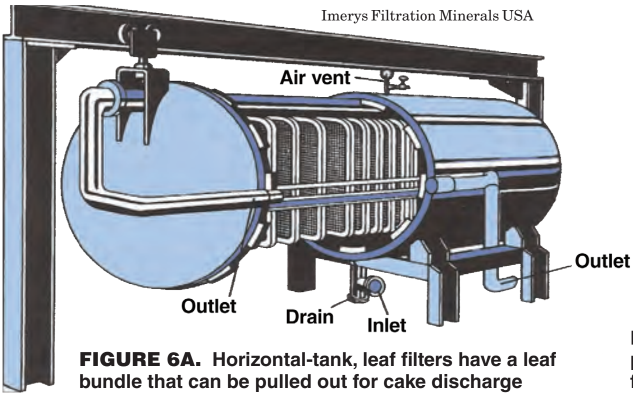


**FIGURE 6A.** Horizontal-tank, leaf filters have a leaf bundle that can be pulled out for cake discharge

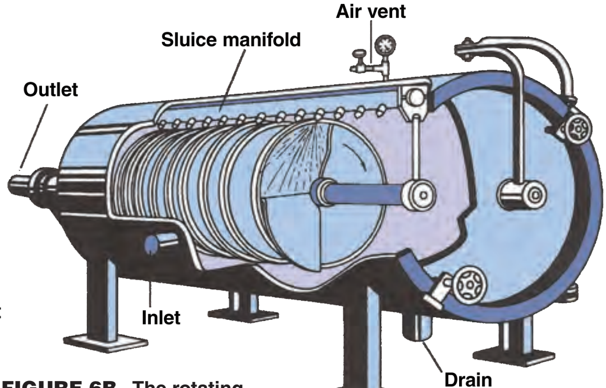


**FIGURE 6B.** The rotating plates of this horizontal-tank, leaf filter are cleaned by sluicing from above

the cake, removing the basket, bottom drop door, tilting the tank, or dissolving the cake with a solvent through a bottom outlet.

The automatic Nutsche filter (Figure 9b) includes an internal agitator or impeller, which is used for reslurrying, compressing the filter cake, smoothing the filter cake, reslurrying the cake during cake washing or extracting and ultimately discharging the filter cake. Dissolving the filter cake in a solvent is also possible.

### Inline cartridge or bag filters

Last but not least are the inline or final filters to remove trace solids, usually either a cartridge or a bag type filter (Figure 10). Cleaning is easy for both types. The cartridge type uses a replaceable or throw away cartridge. The bag filters have a removable felt or cloth bag where the solids are contained. To clean bag filters, remove the bag and either throw it away or wash to remove all solids and replace the bag inside the tank.

## THE MECHANICS OF LIQUID FILTRATION

Liquid filtration is accomplished by separating solids from the process stream at a media interface where filter cake containing the solids is deposited and maintained open-to-flow by filter aids. The tank is the house for the filter plates, which support the media and the cake, which perform the filtration.

There are three filtration techniques to consider as you design the filter station for your process (Figure 11). In some cases, such as for crystalline, easy-to-filter solids, a filter medium alone (cartridge or bag filters) may be sufficient

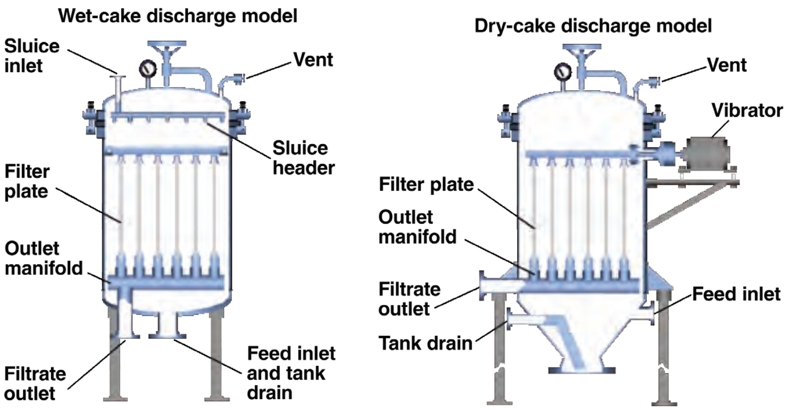


**FIGURE 7.** Vertical tank leaf filters have vertical plates inside a pressure vessel. Filter cake is either discharged wet with a spray from above (left), or dry (right)

for the filtration process. More-difficult-to-filter solids may require precoating, body feed and filtration aids to perform the task at hand. As discussed previously, laboratory test results will help you determine if the filter media alone will produce the desired results or if precoating is required.

### Filtration system designs

***Filtering without precoat.*** In certain applications, due to the nature of the suspended solids, filtration can be performed without a precoat. This situation is considered the exception to the rule of filtration. The filter setup consists of a feed tank, feed pump, filter and piping.

***Filtering with precoat tank only.*** Some applications require only a precoat, so the flow diagram will include a precoat tank with mixer, a pump, the filter and the interconnecting piping with associated valves.

***Filter with precoat and bodyfeed.*** This application requires both a precoat and a bodyfeed tank. Typical filter station setups, shown in Figure 12, will include precoat and bodyfeed slurry tanks, piping, valving, gages and pumps for the filter aids.

For all situations, pressure gauges are installed on the inlet and outlet. The difference in the readings of these two gages (inlet and outlet) is the differential pressure. Close monitoring of differential pressure is necessary to prevent damage to the filter elements by over pressuring. Filter plates are specified for a differential pressure rating, such as 50, 75, or 100 psid. For higher differential pressure ratings, plates have thicker and more heavy duty construction.

Monitoring the cake loading in the filter is important to prevent permanent damage to the filter elements by "bridging" or overloading the filter cake in between the plate elements. Do not exceed the cake capacity rating for the filter, but do leave space for washing and blowing down.

Imerys Filtration Minerals USA

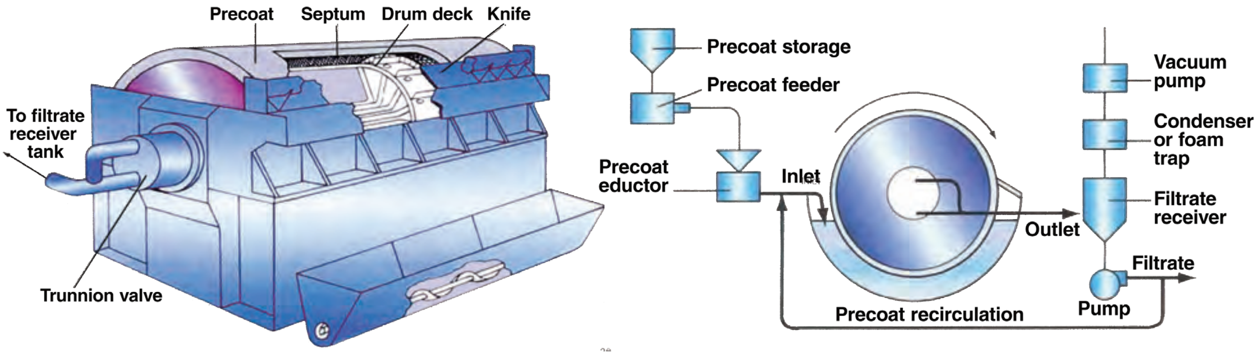


**FIGURE 8. Rotary drum filters continuously perform precoating, filtration and cake washing, drying and discharging for each revolution of the drum. The cutaway diagram on the left shows the mechanical components. The flowsheet on the right shows the feeding and recycling of the precoat**

The effects of overpressuring and overloading cause the most permanent damage to filter elements. This damage bends and warps the filter plates causing problems with filter sealing and performance. Breaks and tears in the filter media lead to bleed-through and lack of filtrate clarity. Problems are compounded when the filter is difficult to clean.

For the filter station that has a precoat tank, the general rule-of-thumb is that the precoat tank should hold about 1.25 times the holding volume of the filter. This ratio allows sufficient volume to fill the filter and the additional volume needed for the interconnecting piping. If the resulting volume of the precoat tank is too large, it is possible to have a precoat tank of about one third or one half of the total volume of the filter. In that case, provisions are made to fill the filter tank and the precoat tank prior to circulating the precoat, so that both tanks are full of liquid.

## Precoating

Clean liquid is used for precoating and is either the same liquid, or one that is compatible with the process feed. The reason for this is that with a clean liquid only the precoat material is deposited on the filter media and there is no contamination from the suspended solids in the feed that would actually defeat the purpose of the precoat.

The precoat tank must have internal baffles to avoid vortexing that will make the precoat pump cavitate by sucking air. The tank should have a properly sized, top-mounted mixer. Consult the local mixer representative or distributor to ensure that the mixer is properly sized, taking into consideration the specific gravity of the liquid, the solids concentration and the abrasive nature of the filter aids. One word of caution about precoat mixing: avoid using air or gas lines inserted into the precoat slurry for mixing, which would introduce air into the filter cake. The air or gas bubbles trapped inside the filter cake, have a tendency to pop, disturbing the filter cake and affecting the clarity of the filtrate.

The amount of precoat material required will depend on the laboratory findings, but normally the rule is to use 0.15 to 0.2 lb for each square foot of filter area. The flowrate required for feeding the precoat material is related to the filter area. A rate of about 1.0 gal/min/ft$^2$ generally gives an even distribution across the plate. The precoat layer should be thick enough to produce the desired results without taking up too much of the cake space available between the filter elements. Select the precoat material that allows the maximum flow in the process with the minimum resistance to flow and pressure drop.

The precoat system needs a good reliable pump, preferably an open-impeller type centrifugal pump. The pump is to carry the precoat as quick as possible with a low pressure drop. Deposit the precoat layer quickly and evenly, but do not compact this layer to cause a high pressure drop and low process flowrate. When precoating the filter, fill the precoat tank and the filter first, thereby allowing the clean liquid to circulate through the filter plates establishing the process flow. Fill the filter with the air vent fully opened to allow displacement of all the air out of the filter tank, avoiding air pockets inside the filter. Avoid any backflow from getting into the filter tank by having a check valve on the filter outlet piping. Also, avoid having any outlet piping at a higher level than the filter tank without a check valve to prevent back flow that will disrupt the filter cake on the filter elements.

Sometimes, depending on the suspended-solid's particle sizes, a double precoat of a fine and then a coarser grade of filter aid is recommended. The recommended procedure is to apply first the finer grade of precoat and then the coarser grade on top. This technique provides a depth-filtration type effect. Your local filter aid representative will help you with this procedure and tell you what distribution to use. Generally the distribution is 60% of the finer grade and 40% of the coarser, but this ratio could vary according to your actual requirements.

When the filter is full and the precoat liquid is circulating from the precoat tank to the filter back to the precoat tank, turn the mixer on and start adding the precoat filter aid material to get it on the filter elements quickly and evenly. Continue this recirculation until the liquid returning to the precoat tank is clear, which should take approximately 10 to 15 minutes. During this procedure the differential pressure across the filter will go from 0 psid to not more than 10 psid.

## Bodyfeeding

If the nature of the solids being filtered tends to blind over the precoat, then once the precoat is formed on the filter media, a bodyfeed is used to introduce additional filter aid to the feed to keep the filter cake porous. While the precoat rate is according to the filter area at about 1–1.5 gal/min/ft$^2$, the bodyfeed rate is according to the percent by weight of suspended solids. This bodyfeed ratio is determined in the laboratory test, and the local filter-aid

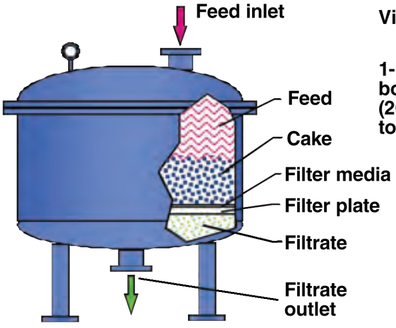


**FIGURE 9A.** A single-plate Nutsche filter is designed to process large volumes of solids that are easy to filter

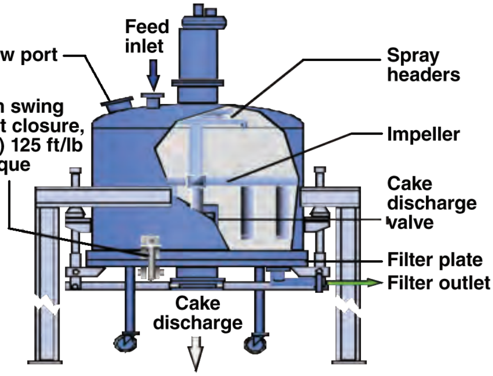


**FIGURE 9B.** The automatic Nutsche filter includes an internal agitator or impeller

representative will offer some guidelines to follow for determining the optimum rate. When in doubt or when there is no laboratory test data, a good starting point is to use a ratio of 1:1 (one part filter aid for each part of suspended solids). The initial results will help determine if this ratio should be increased or decreased. The more crystalline the solids are, the less bodyfeed is required. Sometimes the ratio may be as low as 1:5 (filter aid to suspended solids). If the solids are gelatinous in nature, a higher ratio may be required, such as 2:1. Practice and experience will help with the bodyfeed process specification.

Sometimes, the bodyfeed is added directly to the feed tank, so a separate bodyfeed tank is not required. Also, sometimes the precoat tank is used as the bodyfeed tank. In such case, the precoat tank remains full after precoating, and the bodyfeed material is added. Since the admix requires the mixer to stay on while the bodyfeed is injected, a low speed mixer is used to prevent the erosive nature of the filter aid from reducing its particle size thus affecting the filtration. The bodyfeed pump is a proportioning type pump, a slurry feed pump or a metering pump.

## Filtration

Once the filter is precoated, the filtration process starts. Smooth switching of the valves from the precoat step to the filter step is very important. Always open valves that are to open and then close the valves that are to close to prevent any upsets to the filter cake and the filtration process. If bodyfeed is used, the bodyfeed mix is prepared before hand, during the precoat step. The bodyfeed tank mixer and the bodyfeed pump is turned on to start introducing the bodyfeed into the feed to the filter. The inital flow from the filter is sometimes sent to the precoat tank to ensure that the level is up and ready for the next cycle. Filtration continues with the filtrate going to the holding tank or wherever the process requires. The pressure drop will gradually rise up to the maximum allowable pressure or to a point where the outlet flow decreases, so to continue running the filter is not economical. Again, close attention to the valve sequencing is necessary at the end of this step.

For vertical leaf filters, one more warning comes to mind here. If at any time the filter is stopped, such as while waiting for the next batch to come, it is very important to maintain flow through the filter. Some operators have the idea that if the filter is kept under pressure by closing off the inlet and outlet valves on the filter, maintaining pressure inside the filter is the way to wait for the next batch. This procedure is wrong. The cake on the filter leaves will fall off, slide off and eventually the filter cake is lost in part or in total.

The correct way to wait in between batches is to maintain flow through the filter cake by circulating from the filter outlet back to the inlet. This closed loop circulation is necessary to keep the filter cake on the filter plates and undisturbed. This circulation is achieved by either using a separate circulating pump or providing additional piping to use the feed pump to keep this circulation going. Once the filter is ready to resume filtering, the valves are switched to continue filtering.

After filtration is complete, depending on the process requirements, sometimes a cake wash step is used to extract the mother liquor from the cake with wash liquid or solvent. This cake wash will take 10 or 15 minutes at most, depending on the resistance to flow in the cake. Now the filter is ready for blow down and cleaning.

## Filter cleaning

Depending on the filter features, the filter is cleaned either manually or by the self cleaning features of the filter. For the manually cleaned filters, blow the filter down with air or gas to empty liquids from the filter. Once the filter tank is empty, release the pressure in the filter by opening the vent, leave the drain open, open the filter cover closure and remove the filter elements for manually cleaning and replacing the filter media for the next cycle.

In the case of a self cleaning filter, this step is done either by washing the filter cake off the filter elements using the internal spray or sluice feature or by drying the filter cake with air or gas, opening the filter and using the air vibrator to vibrate the cake off the filter elements. In either case, air or gas is used to drain the filter of the unfiltered liquid left in the tank at the end of the filter cycle. This unfiltered “heel” is returned to the feed tank or to a separate holding tank for that purpose.

In the case of the wet-cake discharge filter, open the filter drain and the air vent and then open the sluice/spray valve. The internal spray will wash the filter cake off the filter elements and down the drain. This process should take approximately 5 to 10 minutes. The filter is then ready for the next cycle and in the standby mode.

In the case of the dry-cake discharge filter, the valve sequence is handled with care to avoid any premature cake drop that will affect the dry-cake discharge process. Open the air blow-down valve, gradually close the feed inlet valve and turn off the feed pump. Blow air or gas through the filter with the outlet valve and drain valve partly closed to keep from losing pressure in the filter suddenly. Drain the filter of the unfiltered heel and once empty, close the drain valve, Gregg-Taylor Associates

**FIGURE 10.** Shown here are a typical bag filter housing, a selection of synthetic cloth and felt bags, and baskets that hold the bags in the housing

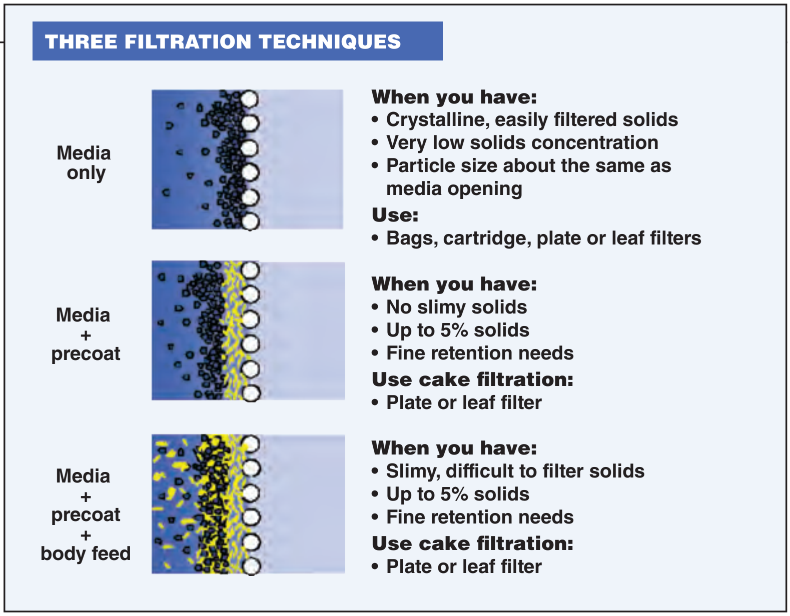


**FIGURE 11.** To perform a liquid filtration process, there are three different techniques to consider when designing the filter station. The technique used will depend on the nature of the solids being filtered

leave the outlet valve partially open and let the air pressure in the filter build up. Once the pressure reaches 30 to 40 psig, quickly open the outlet valve and partially close it again when the air pressure drops to 10 psig. Repeat this procedure for about 10 to 15 minutes in order to dry the filter cake by blowing out as much moisture as possible. Once this cake drying step is concluded, relieve the pressure in the filter, open the drain valve and the air vent, close the air blow down valve and open the filter tank bottom in the vertical tank or the tank closure in the horizontal tank.

Either retract the tank or pull out the leaf bundle exposing the filter leaf bundle with the filter cake and activate the air vibrator to shake the cake off the filter leaves. The discharged filter cake will then fall into a tote bin below the filter to contain the cake. The filter cake discharge is completed. If the filter has an internal washing feature, it is used at this time to wash the filter internals of any residual filter cake or solids.

Running an air vibrator in the filter is always recommended when filling the filter in the beginning of the precoat step to help loosen any precoat material left on the filter media and thus ensure that the filter leaves are clean for a new cycle.

## Filter cake options

Disposal or further handling of the filter cake varies depending on the application. In some applications where the products filtered are very valuable, washing of the filter cake is prescribed to recover as much of the mother liquor as possible to reduce residual product in the filter cake for further processing. This application applies to the plate-type batch filters as well as the Nutsche filters and even to the pressure leaf filters. The washing in place of the filter cake with a solvent is commonly done at the end of the cycle. The solvent or wash liquid is introduced and pumped through the filter cake or pushed through the filter cake with air or gas to displace the mother liquor out of the cake. This procedure is done taking into consideration the pressure drop or resistance to flow at the end of the filter cycle. Generally, as the mother liquor is displaced, the pressure drop is reduced. This displacement procedure normally should take about 10 minutes or slightly more depending on the initial pressure drop and resistance to flow through the filter cake. Laboratory testing is helpful in defining this washing step.

Disposing of the filter cake in some applications can pose problems, depending on the toxicity of the resulting filter cake. In the case of the plate filters, the filter cake is on top of the filter paper. As the filter is cleaned, the filter paper is removed from the filter plate, folded up and disposed into a waste receptacle or sent to be incinerated.

In the pressure leaf filters with a wet cake discharge the resulting slurried cake is sent to either a waste sump or transported off site for ultimate disposal. The cake from filters with dry cake discharge is typically held in the waste tote for transportation off site or sent for further processing either at the plant or another location that may recover certain wanted products from the processed, spent filter-cake waste. Sometimes the non-toxic spent cake is used for landfill or soil conditioning or even animal feed.

## TROUBLESHOOTING

Some of the more common situations or problems that affect the performance of a filter are now covered to assist you in the troubleshooting process.

### Bleedthrough

This situation is identified by different names like cloudy filtrate or particle migration. Sometimes these situations are caused by tears or pinholes in the filter media, or poorly cleaned filter elements with residual cake from the previous cycle that prevents good seals. Channeling due to erosion of the filter cake by the incoming liquid not being properly baffled to prevent disturbing the cake is another cause of the problem. If possible, the filter needs inspection once it is precoated or prior to the cleaning step to determine if the cause of the channeling or bleedthrough is due to pinholes or tears. You can readily see the holes in the cake or the disturbed flow path across the cake where this short circuit has occurred to cause the bleedthrough. Poorly cleaned filter elements leave particles inside the filter element structure that eventually are released by the flow once the differential pressure equalizes.

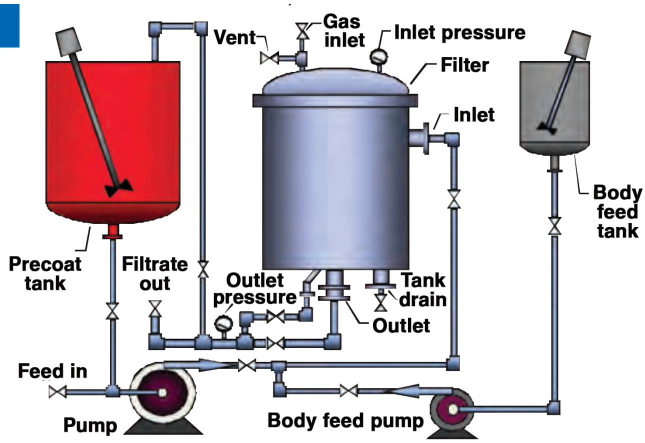


**FIGURE 12A. Shown here is a typical filter station with the associated piping and valves. Pressure gages at the inlet and outlet of the filter are needed to measure the pressure drop**

### Short cycle

The filter cycle is cut short due to a sudden increase in pressure drop, by blinding or plugging and loss of clarity. A sudden increase in pressure drop indicates that the filter cake is blinded due to not enough bodyfeed, a poor precoat or an incorrect choice of filter aid. This problem is identified and resolved in the laboratory by running a bench-scale filter test to determine if an increase or change in bodyfeed or precoat is required to improve cycle time.

### Premature cake drop

This problem affects the dry cake discharge of the filter. A sudden change in flow or improper valve sequencing can cause the cake to drop prematurely leaving gaps in the filter cake. When there are gaps in the filter cake, drying of the cake is affected since the air or gas will short circuit through the crack or missing filter cake. When the filter cake does not dry properly, the cake is wet and mushy and will not discharge, leaving cake on the filter elements that interferes with the next precoat cycle. This leftover cake problem compounds poor cleaning, and the problem snowballs from there requiring opening of the filter and removing the filter elements to manually clean them by pressure washing.

### Process changes

In one instance that I recall, a process was developed by simulating a reaction in the laboratory. The plant was built — including the required process equipment — based on the laboratory results. Prior to starting the plant, the raw material for the reaction in the process was changed without running more tests in the laboratory. The different raw material produced more suspended solids of different characteristics than those originally tested. The results were disastrous, rendering the process equipment incapable of handling the added solids load and complications from these extra solids. So once again, the importance of laboratory testing is stressed.

## PREVENTATIVE MAINTENANCE PROGRAMS

Preventative maintenance in any filter operation, no matter how simple and uncomplicated the operation, is a very important subject. A well executed preventive-maintenance program ensures a long productive life for any filtration equipment, just like that required for other process equipment. In the following section some of the more common recommendations are discussed.

### Filter paper media

The installation of the filter paper onto the plate filters should be done with care to prevent wrinkles, ballooning, tears and folding of the paper. Wrinkles are usually caused by swelling of the filter paper and once compressed between the filter plates, the paper has no place to expand, so wrinkles form in the paper sheet. This problem is avoided by prewetting the filter paper just prior to installing on the filter plates.

Ballooning is caused either by the swelling or by air entrapped under the paper due to filling the filter too fast. If this problem occurs, reduce the flow during the filter fill, thus allowing the air inside the filter plate to evacuate more slowly and completely. Check with the manufacturer of the filter about proper venting recommendations during the filling of the filter. The air entrapped inside the filter plate and under the filter paper tries to push up, and causes the paper to balloon with the trapped air bubbles. These bubbles will flatten as flow starts and pressure rises during filtering and will cause the precoat or cake formed on the filter paper to crack. This crack allows solid particles to break or pass through the filter paper as they did during the initial flow through the filter to form the first precoat layer for coating of the filter paper. Sometimes the bubble under the media breaks causing tears on the filter paper. Also, tears in the filter paper are caused by broken under supports, nicks or imperfections on the metal sealing surfaces in the filter plates. When this problem occurs, inspect the filter paper during the cleaning of the filter and the metal surfaces of the filter plates for any irregularities to determine the cause for cake disturbance.

Folding of the filter paper is due to assembling and redressing the filter plates bundle too fast. Care should be taken to ensure that all the filter papers are lying flat and evenly on the filter plates. A quick visual inspection should show the edges of the paper extending beyond the plates.

### Filter-cloth covers or bags

In filters with cloth covers or cloth bags inspection of the filter cloth is routinely done to look for tears, pin holes or frayed areas that are the cause of problems in the filter performance. Tears on the cloth can occur due to friction or moving parts rubbing against the cloth. Tears, pin holes and fraying of the cloth is also caused by the erosive action of the filter aid. Sometimes the impacting force of the internal sluice or washing jets of the filter cleaning system causes tears or fraying. This damage is prevented by having protecting caps on the filter cloth covers or bags, thus reinforcing the impact areas.

Inspection of the cloth covers or bags for blinded areas, due to improper washing by the internal spray or sluice system, is necessary on a systematic basis. Also, some blinding occurs due to the build up of solids in the weave

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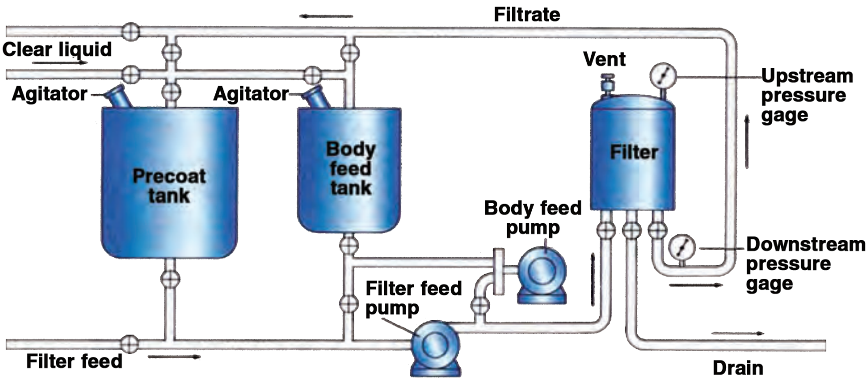


**FIGURE 12B.** Another view of the piping arrangement for a filter system. Centrifugal pumps are used for the feed and precoat, while diaphragm pumps are used for body feed

or threads of the cloth, which is corrected by periodic washing of the cloth bags or covers in industrial washing machines with detergent. Sometimes the cloth material is subject to chemical attack over a long period of use. Changes in the texture of the cloth or stiffness or discoloration of the cloth such as yellowing or browning indicate chemical attack of the cloth.

Handling cloth-covered filter elements with much care is important while installing or removing the filter elements from the filter. Do not drag the cloth-covered filter element on the floor. Do not stack or store the cloth-covered filter elements in a way that shifting or rubbing can occur, and which could damage the cloth covers. Some cloth materials are affected by direct sunlight. Always store cloth covers, cloth bags or cloth-covered filter elements away or protected from direct sunlight. The effects of sunlight exposure are change in color or yellowing and brittleness of the cloth to the point that the cloth itself disintegrates.

### Wire mesh media

In filters with wire-mesh-covered filter elements, inspect for pinholes, tears, fraying, erosion worn areas and broken or loose welds. As stated above for cloth media, possible causes of these potential problems are the same for wire-mesh-covered filter elements. Look for broken under-supports that will cause pinholes and tears on the wire mesh. Friction or rubbing with metal parts can also cause tears, frayed areas and holes. One possible cause of holes in the wire mesh is the erosive action of filter aid, which can act like a sandblast shot wearing away spots or areas on the wire mesh. This wear is evident by closely inspecting the wire mesh for wires worn thin to the point of developing holes. Some of the holes are pinholes while others are areas where the wires are missing altogether with the telltale worn wire hanging around the opening. Another problem to inspect for is broken or loose welds of the wire mesh on the filter elements. Repair the broken welds by welding, spot welding or temporary soldering. Soldering offers a quick temporary repair, but needs follow-up with a proper clean up of the affected area and welding. Sometimes a piece of the same wire mesh is spot welded in place to cover torn spots or holes in the wire mesh.

Since the wire mesh for mesh-covered filter elements are considered permanent, sometimes filter aid particles or solids particles are imbedded inside the filter element structure and under the wire mesh. A simple high pressure wash may not loosen these built-up areas, so ultrasonic or special cleaning is necessary to return the filter elements to like-new conditions. Consult outside sources that perform these types of special cleaning services either on a one time basis or on a routine maintenance schedule.

### Gaskets, seals and O-rings

Other potential problem areas for inspection on a regular preventive maintenance program are O-rings, filter element's outlet couplings, gaskets, seals and packing glands. Check the O-rings for tears, nicks or flattened areas that can cause leaks during filtration. When installing the filter elements in the filter, lubricate the O-rings with a process-liquid-compatible lubricant to prevent damage to the sealing surfaces. Check the filter element outlet couplings to inspect for irregularities on the sealing machined surfaces or for being "out of round." All gaskets in the filter require periodic inspection for tears, nicks or breaks that can cause potential leaks during the operation of the filter.

### Lubrication

Lubrication of moving parts is also an important part of the proper preventive maintenance program of any filter. Good lubrication ensures the trouble free operation of the filter.

### Mechanical service

Cross–tighten and cross-loosen bolts when servicing tank covers. Use torque wrenches to achieve the correct tension for securing pressure vessels and avoid stripping threads on the bolts. Avoid any undue stress or forceful operation of the filter to prevent unnecessary wear and tear on the filter parts.

## FINAL REMARKS

Good training for your production staff is time well spent to produce filtered products that meet specifications cost effectively and keep equipment operating efficiently.

Remember your best source for help to achieve the successful operation of the filter, trouble and problem free, is your filter equipment manufacturer or a filter consultant. Help and assistance is only a phone call or an email away. ■

*Edited by Gerald Ondrey*

### Author


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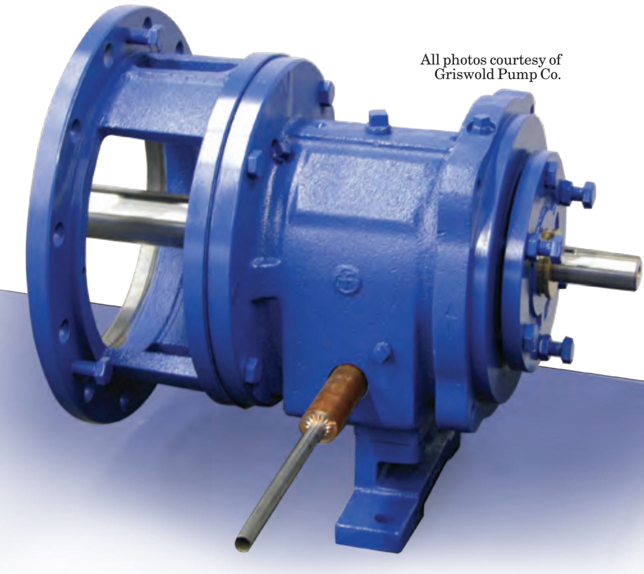
# Making Pump Maintenance Mandatory

## Transfer pumps must be kept in optimum shape to handle harsh chemical processing operations



All photos courtesy of Griswold Pump Co.

**FIGURE 1.** Temperatures above 350°F require a finned-tube oil cooler to cool the bearing frame

**Edison Brito,** Pump Solutions Group

One of the key components in the operational success of chemical process industries (CPI) facilities is the transfer pump. These pumps must handle a wide variety of materials under a broad range of operating conditions. These diverse operational conditions may include harsh and corrosive environments as well as the following:

- Changes in ambient temperatures and other weather conditions, such as humidity
- Line shock from piping that is not anchored down properly
- Piping systems that have inhibitive sharp bends instead of the preferred gentle curves
- Changes in the product type being pumped
- Changes in product viscosity
- High volume (such as unloading a 50,000-gallon tanker) at high flowrates (4,000 gpm, for example)
- Changes in product velocity and force
- Changes in hydraulic operating point

In all of these situations, pumps must deliver around-the-clock reliability to avoid costly equipment downtime that can have a huge adverse effect on a facility's operational effectiveness and profitability.

Pumps will perform at their very best only if proactive steps in both preventive and protective maintenance are established and implemented. This article demonstrates how attention to a strict maintenance routine can keep pumps running reliably in chemical-processing environments that put the pump's operation under constant threat, with the ultimate goal of optimizing pumping-system efficiency and effectiveness. Specifically, centrifugal and air-operated diaphragm pumps are discussed here.

### CENTRIFUGAL PUMPS

For decades, the number one pump-style choice by operators of CPI facilities has been centrifugal-pump technology. Centrifugal pumps meet the needs of the many and varied transfer operations that are found within the CPI because their design enables them to handle many fluid-transfer applications. Historians tell us that the first machine that can accurately be classified as a centrifugal pump was a mud-lifting apparatus that appeared in Europe as early as 1475 A.D. [*1*] A straight-vaned centrifugal pump was developed in the late 1600s by Denis Papin, a French inventor and physicist. The curved-vane centrifugal pump, which most closely resembles current-day centrifugal-pump technology, was brought to market in 1851 by British engineer John Appold. Appold's design, which was three times more efficient than other pump technologies at the time, won him a "Council Medal" at the Great Exhibition at Crystal Palace in London, England, that year.

Since their earliest invention, centrifugal pumps have moved liquids through the use of centrifugal force. This makes them kinetic machines in which pumping energy is continuously imparted to the pumped fluid by means of a rotating impeller, propeller or rotor. More specifically, centrifugal pumps use bladed impellers to transfer rotational mechanical energy to the fluid, primarily by increasing the fluid's kinetic energy, or angular momentum, while also increasing the potential energy (static pressure). The gathered kinetic energy is then converted into usable pressure energy in the discharge collector [*2*]. In other words, a centrifugal pump transforms the energy of "velocity" transferred to the fluid by the impeller into energy of "pressure" in the casing or diffuser(s).

Currently, the two most common styles of centrifugal pumps are:

- ***End-suction*** — These pumps are ideal for thin liquids and the top choice for most water-pumping applications

## THE FUTURE IS NOW FOR PUMP MAINTENANCE

There is absolutely no question that the invention and growth in popularity of the Internet has affected the lives of most everyone on Earth in one way or another. One of the most important is the immediacy in which tasks that used to take hours or days can now be completed in a matter of seconds, all from the comfort of home.

The "right now" effect of the Internet has also trickled down to the world of industrial transfer pumps. In years past, whenever a pump broke down, or routine maintenance needed to be performed, the facility manager had two choices: dig around for the installation, operation and maintenance (IOM) manual, identify the problem and then go about trying to fix it; or call the manufacturer or distributor, then wait for a service technician to arrive onsite to assess and address the problem.

Realizing the power that the Internet can possess in instances like these, many pump manufacturers are developing maintenance videos for their distributors and end-users that are designed to help them properly rebuild or maintain their equipment. Now, for a task that may have taken days to complete, there may be a ten-minute video available on the manufacturer's or another Website, for example, that shows the proper way to maintain or fix a pump.

Instead of the frustration that used to accompany a pump breakdown or maintenance issue, effective use of the Internet can provide a very helpful, time-efficient way to present maintenance tips and repair steps to service technicians. ❑


**FIGURE 2.** The oil level must be at the halfway point in the sight glass

- ***Self-priming*** — This type of centrifugal pump has the ability to lift fluid, which gives it an advantage when the source is below the centerline of the pump

Both end-suction and self-priming pumps, as well as other pump styles, may also meet the centrifugal-pump manufacturing criteria established by the American National Standards Institute (ANSI) in 1977. With that standard in mind, ANSI centrifugal pumps are engineered for operational flexibility and durability.

No matter the operational atmosphere where these types of pump are being used, a routine maintenance program will extend the life of the pump since well-maintained equipment lasts longer and requires fewer and less-expensive repairs. In fact, because many CPI pumping systems can often have life spans of 15 years or longer, it is now a valid consideration for the plant operator to perform a life-cycle cost (LCC) analysis that factors in the lifetime costs of maintenance, along with purchase, installation, energy usage, operation, downtime, environmental and other costs when choosing the proper pump technology for the operation. According to the Hydraulic Institute, while energy, at 40%, might represent the highest expected pumping-system-related expense in an LCC analysis, the second-most costly is often maintenance, at 25%, which is well ahead of initial pump cost and operating costs that are both estimated at 10% of life-cycle costs [*3*].

## Maintaining an edge

In order to obtain optimum working life from a centrifugal pump, regular and efficient maintenance is required [*4*]. When the pump is purchased, the pump manufacturer will typically advise the plant operator about the frequency and extent of routine maintenance, but it is the operator who has the ultimate final say about how his facility's maintenance routine will function, or in other words, whether it will consist of less frequent but more major attention, or more frequent but simpler servicing. The potential cost of unexpected downtime and lost production is also a significant item when determining the total LCC of a pumping system. Again, the facility's maintenance routine should determine what steps should be followed when an unexpected breakdown occurs, while a post-repair assessment should identify areas where a more-proactive maintenance regime might have prevented the breakdown and resulting downtime.

The facility operator must also be certain to keep a detailed record of any preventive maintenance that was performed and repairs that were needed for each pump. This information should be kept in order to create an easily accessible record that can help diagnose problems and eliminate, or minimize, any future equipment downtime.

Moving into the nuts and bolts of centrifugal-pump maintenance, routine preventive and protective maintenance practices should include, at a minimum, the monitoring of the following [*5*]:

***Bearing and lubricant condition.*** Monitor bearing temperatures (Figure 1), lubricant level and vibration. The lubricant should be clear with no signs of frothing, while changes in bearing temperature may indicate imminent failure.

***Shaft seal condition.*** The mechanical seals should show no signs of visible leakage. Any packing should leak at a rate of no more than 40 to 60 drops per minute.

***Overall pump vibration.*** Imminent bearing failure can be preceded by a change in bearing vibration. Unwanted vibration can also occur due to a change in pump alignment, the presence of cavitation or resonances between the pump, its foundation or the valving located in the suction and discharge lines.

***Differential pressure.*** The difference between the pressure readings at the discharge and the suction of the pump will provide the total developed head pressure of the pump. A gradual decrease in the developed head pressure of the pump can indicate that the impeller clearance has widened, which requires adjustments to restore the pump's intended design performance: impeller clearance adjustment for pumps with semi-open impeller(s) or replacement of the wear ring(s) for pumps with closed impeller(s).

Also worth noting is that maintenance and monitoring intervals should be shortened if the pump is used in severe-service conditions, such as with highly corrosive liquids or slurries.

## Quarterly maintenance

The following should be done every quarter:

- Check the pump's foundation and hold-down bolts for tightness
- The oil should be changed after the first 200 hours of operation for a new pump then after every three months or 2,000 operating hours, whichever comes first
- Regrease bearings every three months or 2,000 operating hours, whichever comes first
- Check the shaft alignment

## Annual maintenance

A pump's performance should be checked and recorded in detail at least once a year. Performance benchmarks should be established during the early stages of a pump's operation, when the parts are new and the installation adjustments are correct. This benchmarking data should include the following:

- The pump's developed head pressure, as measured at the suction and discharge pressures, for three to five conditions should be obtained. Where possible and practical, a no-flow reading is a good reference and should be included
- Pump flowrate
- Motor amperage draw and voltage, corresponding to the three to five operating conditions mentioned above
- Vibration signature
- Bearing housing temperature

When the annual assessment of a pump's performance is made, any changes in the benchmarks should be noted and used in determining the level of maintenance that may be required to get the pump back to operating at its best efficiency.

When considering centrifugal-pump operation and maintenance requirements, one thing must be kept in mind: all pump bearings will fail eventually [5]. However, the cause of bearing failure is more often than not a failure of the lubricating medium, not equipment fatigue. Therefore, particular attention needs to be paid to bearing lubrication in order to maximize bearing and, by extension, pump life.

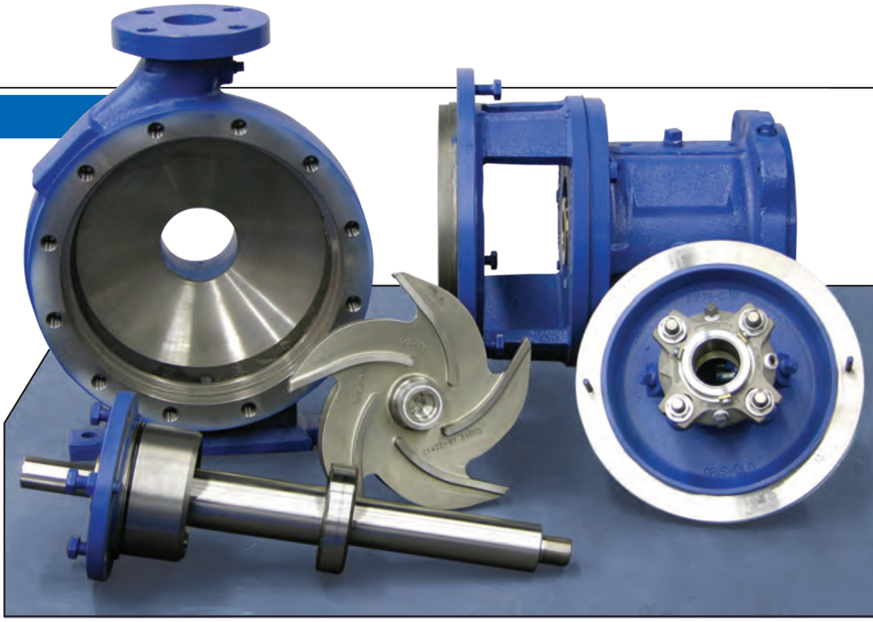


**FIGURE 3.** Major components can be laid out for inspection

If an oil is being used for bearing lubrication, remember to use only non-foaming and non-detergent oils. The proper oil level is at the mid-point of the bull's-eye sight glass on the side of the bearing frame (Figure 2). It is important to avoid over-lubrication as it can be just as damaging as under-lubrication. Excess oil will cause a slightly higher horsepower draw and generate additional heat, which can in turn cause frothing of the oil. Any cloudiness observed when checking the condition of the lubricating oil can be an indication that an overall water content of greater than 2,000 ppm is present. This is commonly the result of condensation. If this is the case, the oil needs to be changed immediately.

If the pump is equipped with regreaseable bearings, be certain to never mix greases of differing consistencies or types. Also note that the shields must be located toward the interior of the bearing frame. When regreasing, ensure that the bearing fittings are absolutely clean as any contamination will decrease bearing life. Overgreasing must also be avoided because this can cause localized high temperatures in the bearing races and create caked solids. After regreasing, the bearings may run at a slightly higher temperature for a period of one to two hours.

In instances where the operator of a chemical-processing facility may need to replace a part, or parts, on a malfunctioning pump, these circumstances should also be treated as an opportunity to examine the pump's other parts for signs of fatigue, excessive wear and cracks (Figure 3). At this time, any worn parts should be replaced if they do not meet the following part-specific tolerance standards:

***Bearing frame and foot*** — Visually inspect for cracks, roughness, rust or scale. Check machined surfaces for pitting or erosion.

***Bearing frame*** — Inspect tapped connections for dirt. Clean and chase threads as necessary. Remove all loose or foreign material. Inspect lubrication passages to be sure that they are open.

***Shaft and sleeve*** — Visually inspect for grooves or pitting. Check bearing fits and shaft runout, and replace the shaft and sleeve if worn or if the tolerances are greater than 0.002 in.

***Casing*** — Visually inspect for signs of wear, corrosion or pitting. The casing should be replaced if wear exceeds 1/8-in. deep. Check gasket surfaces for signs of irregularities.

***Impeller*** — Visually inspect the impeller for wear, erosion or corrosion damage. If the vanes are worn more than 1/8-in. deep, or if they are bent, the impeller should be replaced.

***Frame adapter*** — Visually inspect for cracks, warpage or corrosion damage and replace if any of these conditions are present.

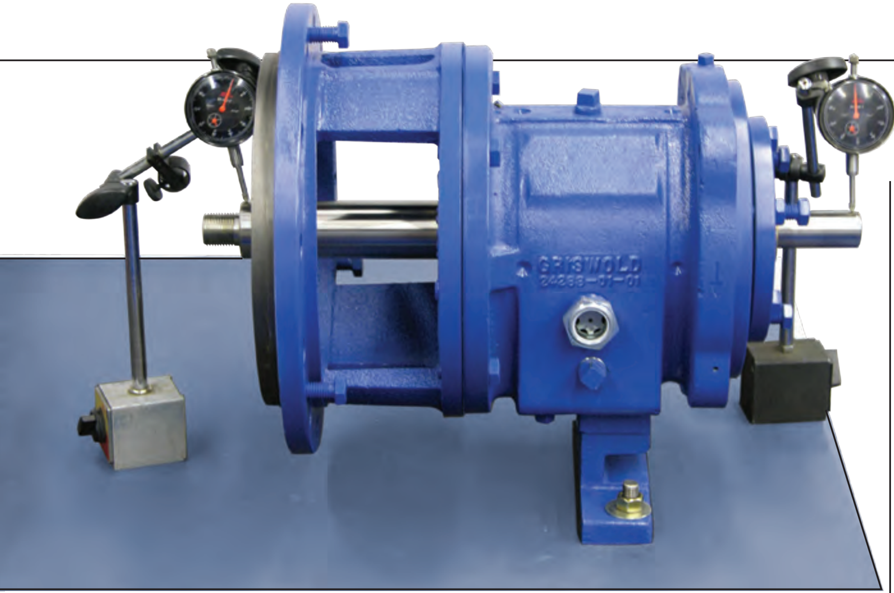



**FIGURE 4.** Shaft run-out must be checked at both the coupling end and the mechanical seal end. Maximum run-out is 0.002 in. total indicator reading (TIR)

***Bearing housing*** — Visually inspect for signs of wear, corrosion, cracks or pits. Replace housings if worn or out of tolerance.

***Seal chamber/stuffing box cover*** — Visually check for cracks, pitting, erosion or corrosion, paying special attention to any wear, scoring or grooves that might be on the chamber face. Replace if worn more than 1/8-in. deep.

***Shaft*** — Check the shaft for any evidence of corrosion or wear. Check the shaft for straightness, noting that the maximum total indicator reading (TIR) at the sleeve journal and coupling journal cannot exceed 0.002 in. (Figure 4).

Implementing all of these maintenance recommendations may seem daunting, but it is only through a routine such as this that CPI operations can maximize the service life of equipment while enhancing the safety of plant personnel and the environment.

## DIAPHRAGM PUMPS

The invention of air-operated double-diaphragm (AODD) pump technology in 1955 was a textbook example of necessity being the mother of invention. The invention of AODD pump technology was the climax in an ongoing search for a way to effectively and efficiently pump substances with a wide range of viscosities — from water to slurries to cement — at a wide range of flowrates. The technology, which was said to have been "conceived out of necessity, born in the arms of innovation, and inspired by sheer will and determination," operates by displacing fluid from one of two liquid chambers upon each stroke completion through the action of an air valve and a pair of diaphragms that are connected by a common shaft [7].

This simple design, where the diaphragms act as a separation membrane between the compressed air supply and the liquid, has stood the test of time. Evidence of this is borne out everyday at CPI facilities around the globe where AODD pumps — whether metal or plastic, ductile iron or stainless steel, clamped or bolted — play a critical role in ensuring that product transfer of thin liquids, corrosives, abrasives, particle-laden slurries and more continues apace in a cost-effective, energy-sensitive, environmentally friendly manner.

Like all other types of pumping systems, no matter their method of operation, AODD pumps operate at their best efficiency when maintained properly, either through preventive or protective maintenance. Thankfully for the operators of CPI facilities, the AODD pump's design means that maintenance is easily and efficiently performed.

A preventive-maintenance schedule should be set up for the following AODD pump parts to ensure that the pump is serviced prior to pump wear [8]:

- Diaphragms
- Valve seats
- Valve balls
- O-rings

When performing routine AODD-pump maintenance checks, there are three main areas that demand attention:

***Air valve piston/spool and casing*** — Ensure that the piston/spool can move freely and remove any debris.

***Diaphragms*** — Make sure there is no swelling, cracking or other damage to the diaphragm surface.

***Balls/seats/O-rings*** — Make sure that no swelling, cracking or other damage is apparent, and lubricate the shaft, if needed.

Another top-of-mind maintenance concern is seal replacement since proper seal installation is critical to pump performance. Care must be taken to ensure that seals are placed in the proper grooves and not damaged during installation. Incorrect seal location will render the pump inoperable, while damaged seals may cause decreased performance and shorter seal life.

## Troubleshooting

Due to the design of AODD pumps, there are only a few rare complications that may surface during their operation. Fixing these problems can be a simple process in many cases. Below you will find a list of potential problems and solutions that pump users might find in CPI operations [7]:

***Pump will not run or runs slowly*** — Solutions: Check for obstructions in the air passageways or objects that can obstruct the movement of internal parts.

***Pump runs but little or no product flows*** — Solutions: Check for pump cavitation, slow down pump speed to allow material to enter pumping chambers, then increase speed accordingly. Check for sticking ball check valves and, if necessary, replace check valves with proper elastomers. Check to make sure all suction connections are air tight.

***Air bubbles in pump discharge*** — Solutions: Check for ruptured diaphragm. Check tightness of clamp bands, especially at the intake manifold.

***Product comes out air exhaust*** — Solutions: Check for ruptured diaphragm. Check tightness of large clamp bands. Check tightness of piston plates to shaft, if applicable.

***Pump rattles*** — Solutions: Create false head or suction lift.

Over the years, the AODD pump technology has been modified to fit specific pumping applications. One of the modifications that has benefited chemical processors has been the introduction of plastic, solid-body AODD pumps. The construction of these pumps allows them to deliver increased product capacity and optimized flow patterns, all while using less air. Their heavier construction also eliminates the "wander" that can plague lighter oscillating pumps and can often result in product leakage.

Like their traditional AODD brethren, these unique pumps must be maintained properly in order to reach their full product-transfer potential. A key area that plant operators should focus on for preventive maintenance are the housing bolts. Instead of single bolts pressing punctually against the housing, the bolts are tightened against a diaphragm-sized ring. These rings must be inspected and, if damaged, replaced in order to ensure that the housing bolt force is evenly spread across the pump's surface, as intended.

AODD pumps are well-suited for the CPI thanks to their ability to perform in even the harshest operating conditions, but like all pumps, their operational performance is only enhanced when proper maintenance precautions are taken. So, while AODD pumps can be the answer for many fluid-handling requirements in chemical processing, it is only those that are maintained regularly and properly that have the longest life-cycle and lowest total cost of ownership. ■

*Edited by Dorothy Lozowski*

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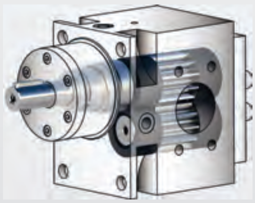

# Determining Packing Height With Accuracy

**Theoretical stages are useful for process design calculations, but transfer units bring much needed clarity to equipment selection and specification**

Kenneth Graf
Koch-Glitsch, LP

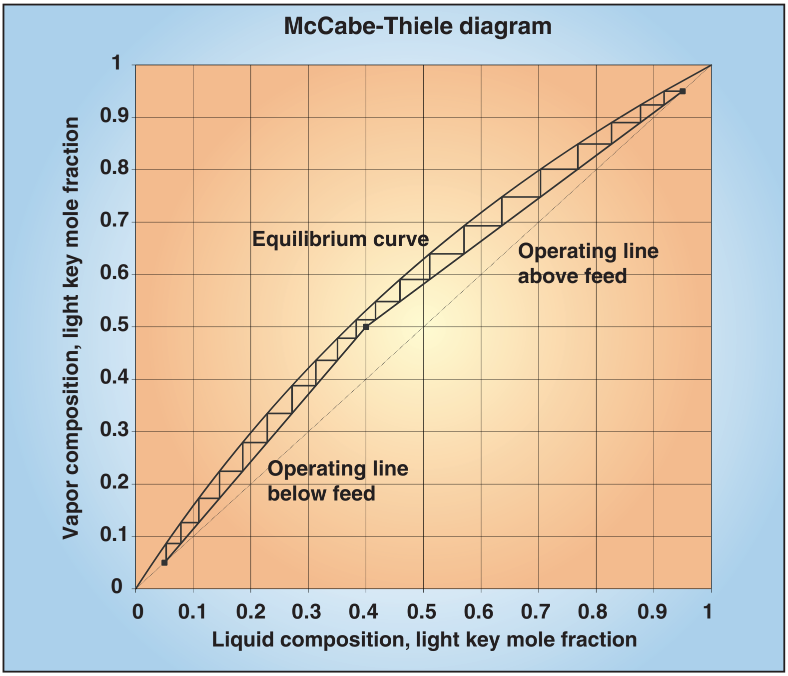


**FIGURE 1.** A McCabe-Thiele diagram illustrates theoretical stages in binary distillation

Equilibrium stage simulations are the nearly universal process design tool for mass transfer columns that contact vapor and liquid in countercurrent flow. Whether the service is absorption, stripping, distillation, fractionation, quench or evaporation, equilibrium stage models make mass and heat balances easy. They quickly estimate stream conditions and physical properties. They are easily altered, so a change to any design parameter can be instantly assimilated into equipment and stream properties.

When it comes to the actual design of mass transfer columns, however, the use of theoretical stage simulations can leave engineers perplexed about what packing height to use, and can lead engineers to believe that packing efficiency is a bewildering art devoid of logic. A better procedure begins with process design by equilibrium stages, followed by conversion of theoretical stages to transfer units, followed by equipment choice and design. This procedure results in complete process design, correct expression of the mass transfer task and logical choice of equipment.

**Limitations of equilibrium stages**

Many packed column designs for distillation, absorption and stripping follow this path:

1. The task of the column is first defined by an equilibrium stage simulation. (Equilibrium stages are also called theoretical stages or theoretical plates.)
2. The column task is expressed as a profile of column internal loadings and as the theoretical stage needs of the column.
3. Packing rating software is used to choose a packing and a column diameter and to estimate the packing pressure drop.

Then comes the question: What HETP (height equivalent to a theoretical plate) will convert the equilibrium stage needs into packed bed depths? The answer to this question often seems unattainable and vague, and it may seem to lack engineering principle.

You may have heard statements such as, "The HETP of this packing in low-relative-volatility distillation is 300 mm." What about other services, such as absorption, stripping, and high-relative-volatility distillation?

You may have heard that the HETP for a specific service is two or three times the HETP shown in published literature or in a standard packing test. Why is there such a difference? Is the proposed packing inferior? Is the recommended HETP excessively conservative? Are the published data grossly optimistic?

Some equipment design equations separate the magnitude of an assigned task from the performance of the equipment. In a simplified example of single-phase heat exchanger design, the required task can be described as a heat duty ($Q$) and the log mean temperature difference ($LMTD$); these issues have nothing to do with equipment. The exchanger performance is described as an overall heat transfer coefficient ($U$). Together, the required task and the exchanger performance indicate the required heat-transfer surface area ($A$):

$$A = (Q/LMTD) / U \tag{1}$$

With similar rationale, many column designers think that the number of theoretical stages ($NTS$) is a complete description of the mass transfer task. They view $HETP$ as a property of the packing. They believe that they have separated the task from the equipment performance by counting theoretical stages and then asking for the packing $HETP$ to find the total packed bed height ($H$).

$$H = HETP \times NTS \tag{2}$$

But the number of theoretical stages does not completely define the task of the packing. The statement of required stages and the subsequent question of $HETP$ have not properly separated equipment performance from the task to be done. So the $HETP$ value needs to contain a correction for a poorly quantified task. $HETP$ values can seem illogical because the $HETP$ is not just a property of the packing; it also depends on the task to be done, and on how poorly $NTS$ has quantified the task!

## Mass transfer refresher

The mass transfer concepts and equations used herein are covered thoroughly in various mass transfer textbooks, including Treybal [1] and Henley and Seader [2]. These texts also describe the McCabe-Thiele [3] binary distillation diagram, which illustrates distillation stages and equilibrium driving forces. Figure 1 shows an example McCabe-Thiele diagram for a 20-stage distillation.

Above a column feed, we focus on purification of the vapor and on vapor composition ($y$). The vertical distance between the operating line and the equilibrium line represents the composition driving force for mass transfer, ($y^*$–$y$). One equilibrium stage is movement of a distance ($y^*$–$y$) along the operating line, where $y$ and $y^*$ are measured at the beginning of the stage. The binary McCabe-Thiele diagram shows $x$ and $y$ values of the light component, but we are more interested in the values of $y$, $y^*$, and ($y$–$y^*$) for the heavy key component.

Below the feed, we focus on purification of the liquid and on liquid composition $x$. The horizontal distance between the operating line and the equilibrium line represents the composition driving force for mass transfer, ($x$–$x^*$). One equilibrium stage is movement of a distance ($x$–$x^*$) along the operating line, where $x$ and $x^*$ are measured at the beginning of the stage.

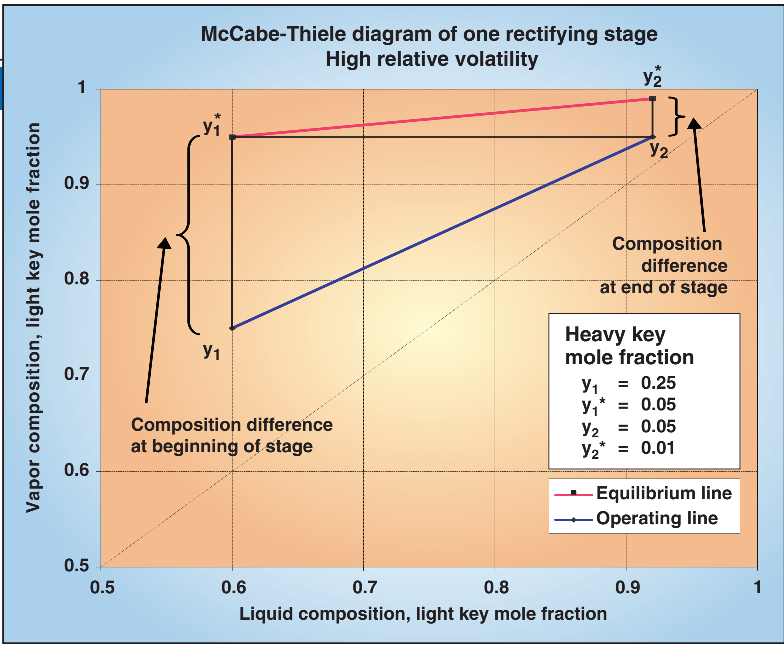


**FIGURE 2.** In high-relative-volatility distillation, the mass transfer driving force can change severely over one theoretical stage

## Transfer units

In most packed columns, the mass transfer rate can be expressed by Equation (3) for the heavy key or absorbed component in the vapor, or Equation (4) for the light key or stripped component in the liquid. Elevation ($h$) is positive in the direction of flow, which is upward for vapor and downward for liquid.

Vapor mass transfer rate ($G$)

$$-G\,dy = K_y aS\,(y-y^*)\,dh \tag{3}$$

Liquid mass transfer rate ($L$)

$$-L\,dx = K_x aS\,(x-x^*)\,dh \tag{4}$$

The mass transfer coefficients $K_y$ and $K_x$ depend on many parameters, but not on $x$ or $y$. In many columns, $L$ and $G$ are nearly constant over large sections of the column. (If this is not true, the adjustments do not change the major points of this paper, but they are not covered here.) Integration of Equations (3) and (4) provides the packed bed height $H$ needed to change from composition $Y_1$ to $Y_2$, or $X_1$ to $X_2$:

For absorption and rectifying distillation columns:

$$H = \left(\frac{G}{K_y aS}\right)\int_{Y_1}^{Y_2}\frac{-dy}{(y-y^*)} \tag{5}$$

For stripping and stripping distillation columns:

$$H = \left(\frac{L}{K_x aS}\right)\int_{X_1}^{X_2}\frac{-dx}{(x-x^*)} \tag{6}$$

***Number of transfer units (NTU).*** The above integrals in Equations (5) and (6) are dimensionless numbers called the number of transfer units, $NTU_{OG}$ and the $NTU_{OL}$, respectively.

For the heavy key or absorbed component ($NTU_{OG}$):

$$NTU_{OG} = \int_{Y_1}^{Y_2}\frac{-dy}{(y-y^*)} \tag{7}$$

For the light key or stripped component ($NTU_{OL}$):

$$NTU_{OL} = \int_{X_1}^{X_2}\frac{-dx}{(x-x^*)} \tag{8}$$

***Height of a transfer unit (HTU).*** The expressions outside the integrals

| TABLE 1. QUICK CONVERSION BETWEEN THEORETICAL STAGES TO TRANSFER UNITS | |
|---|---|
| If the key component declines by this factor from stage to stage: | Then the ratio of transfer units to stages, NTU/NTS, is: |
| 2.0 | 1.39 |
| 3.0 | 1.65 |
| 4.0 | 1.85 |
| 5.0 | 2.01 |
| 6.0 | 2.15 |
| 7.0 | 2.27 |
| 10.0 | 2.56 |

of Equations (5) and (6) are called the height of a transfer unit, $HTU_{OG}$ and $HTU_{OL}$, respectively. This paper focuses on columns where *HTU* can be estimated empirically, so we will not need terms like $G$, $K_y$, $L$, $K_x$, $a$ and $S$.

$$H = HTU_{OG} \times NTU_{OG} \quad \textbf{(9)}$$

$$H = HTU_{OL} \times NTU_{OL} \quad \textbf{(10)}$$

The subscript *O* (for "overall") indicates bulk phase compositions, not phase interface compositions. The subscripts *G* and *L* indicate use of *y* or *x* compositions, respectively.

Transfer units correctly separate the task (*NTU*) from the equipment performance (*HTU*). The task *NTU* depends on the compositions of the liquid and vapor, the relative volatility and the desired separation, but *NTU* has nothing to do with the equipment that must accomplish the task. The *HTU* depends on the packing, on flow rates, on physical properties and on liquid distribution quality, but it does not depend on the separation desired, the relative volatility, the reflux composition or the lean solvent loading.

Because transfer units are an accurate expression of a mass transfer task, *HTU* values will appear more sensible and more consistent than *HETP* values. This paper shows ways to evaluate the integral for *NTU* and provides guidelines to estimate the *HTU* values in various situations.

## LOW-RELATIVE-VOLATILITY DISTILLATION

The McCabe-Thiele diagram in Figure 1 represents a hypothetical low-relative-volatility distillation column. It can also represent a packing efficiency test, although most efficiency tests occur at total reflux, where the operating line is the 45-degree line.

Consider one of the theoretical stages on the right side (above the feed) of the diagram. Note that the equilibrium line and the operating line are nearly parallel over the short range of each stage. This means that ($y^*$–$y$) is constant at the beginning of the stage, in the middle of the stage, and at the end of the stage. Although the McCabe-Thiele diagram represents the light key compositions, it is also true for the heavy key component. The mass transfer driving force is the constant ($y_1$–$y_2$) over the entire stage.

Consider how many transfer units this theoretical stage represents. Because ($y$–$y^*$) is the constant ($y_1$–$y_2$), Equation (7) reduces to:

$$NTU_{OG} = \int_{y_1}^{y_2} \frac{-dy}{(y-y^*)} = \frac{1}{(y_1-y_2)} \int_{y_1}^{y_2} -dy = \frac{(y_1-y_2)}{(y_1-y_2)} = 1 \quad \textbf{(11)}$$

***For low-relative-volatility distillation, each theoretical stage equals one transfer unit.*** So in low-relative-volatility rectification, the number of theoretical stages (*NTS*) is also the number of transfer units $NTU_{OG}$. The equilibrium stage count *NTS*, which is important in mass and heat balances and in separation calculations, is the same as $NTU_{OG}$, which is important to mass transfer. And, the *HETP* value is the same as the $HTU_{OG}$ value.

Over many years, hundreds of low-relative-volatility distillation tests have shown that many packings display about the same *HETP* over a wide range of systems and rates. Even widely varying pressure does not cause much *HETP* variation, although high pressures can imply high liquid rates that reduce the efficiency of structured packing. This principle has suggested the use of a single, characteristic *HETP* value for each packing. As an example, a structured packing product brochure [*4*] lists characteristic HETP values for two families of structured packing. This principle tends to apply to random packing and to sheet-type structured packing, but not to gauze and mesh type packing.

The consistency of HETP in low-relative-volatility distillation has simplified design of such columns, and engineers encounter few problems in proceeding from equilibrium stage calculations to packed bed heights. Engineers don't even think about transfer units, and they don't realize that the equivalence of equilibrium stages and transfer units has made their designs easier.

Low-relative-volatility distillation is not the focus of this paper. The topic of low-relative-volatility distillation is raised here because the hundreds of low-relative-volatility packing tests have provided a database of $HTU_{OG}$ values that are useful beyond the realm of low-relative-volatility distillation.

## HIGH-RELATIVE-VOLATILITY DISTILLATION (RECTIFICATION SECTION)

Consider the rectifying section (above the feed) of a high-relative-volatility distillation column, and the heavy key component concentration in the vapor phase. Packing does not provide theoretical stages of vapor-liquid contacting. Packing simply contacts the two phases and lets the non-equilibrium compositions cause mass transfer between the phases. At any vapor-liquid interface in the column, the local mass-transfer rate is proportional to the driving force. In rectification, Equations (3), (5), (7), and (9) apply. We could reasonably say that packing provides transfer units, but not theoretical stages.

Counting theoretical stages does not take into account the effect of mass transfer progress on driving force. Theoretical stages set the mass transfer task of the packing in each stage according to the driving force of the incoming vapor. If the driving force diminishes as mass transfer proceeds in the packing, theoretical stages do not recognize the slowing of mass transfer in proportion to the diminishing driving force.

In the heat transfer analogy of Equation (1), suppose some illogical engineers decided to work with only one temperature differential $(T–t)_1$ at one end of heat exchangers:

$$Q = U\,A\,(T–t)_1 \quad \textbf{(12)}$$

Suppose these engineers knew that ($T$–$t$) changes along the exchanger as heat transfer proceeds, but they refused to use an average ($T$–$t$), such as *LMTD*, instead of the fixed $(T–t)_1$

in Equation (12). Wouldn't values of $U$ vary severely to compensate for the error as $(T–t)_1$ misrepresents the average $(T–t)$? Wouldn't correlation and prediction of $U$ be nearly impossible for heat exchanger design? This error and consequence are analogous to the error and consequence of using *HETP* in mass transfer.

Figure 2 illustrates one equilibrium stage of a binary high-relative-volatility distillation. Vapor entering the stage has a driving force of 0.20, and 0.20 becomes the expected composition change of the stage. As mass transfer begins and the vapor moves up the operating line, the driving force declines. At the end of the stage, the driving force is only 0.04, so the mass transfer slows to one-fifth of the initial rate. Over the stage, the composition change of 0.20 must be attained with an average driving force much less than 0.20. This stage will require more packing than a stage in low-relative-volatility distillation, where the driving force stays constant over each stage.

Transfer units account for the change in mass transfer rate that is caused by changing driving force. We can evaluate the number of transfer units that the theoretical stage in Figure 2 represents for the heavy key component. Because the operating line and the equilibrium line are both locally straight, the integral in Equation (7) is simplified by the use of log mean driving force:

$$NTU_{OG} = \int_{y_1}^{y_2} \frac{-dy}{(y-y^*)} = \frac{(y_1 - y_2)}{\log\ \text{mean}\left[(y_1 - y_1^*),(y_2 - y_2^*)\right]} \quad \textbf{(13)}$$

Where

$$\log\ \text{mean}\left[(y_1 - y_1^*),(y_2 - y_2^*)\right] = \frac{\left[(y_1 - y_1^*)-(y_2 - y_2^*)\right]}{\ln\left[(y_1 - y_1^*)/(y_2 - y_2^*)\right]} \quad \textbf{(13A)}$$

The composition change $(y_1–y_2)$ is (0.25–0.05) = 0.20. The log mean $(y–y^*)$ is the log mean of (0.25–0.05) and (0.05–0.01), or 0.0994. $NTU_{OG}$ is (0.20)/(0.0994) = 2.01. So the *one* theoretical stage in Figure 2 is *two* transfer units.

Evaluation of $NTU_{OG}$ for the rectification section of a distillation column is not difficult. An equilibrium stage simulation can provide the heavy key molar $y$ compositions on each stage. The simulation is valuable in two respects:

1. It provides the $y^*$ equilibrium compositions above and below each stage; these are the $y$ compositions on the next higher stages.
2. It divides the distillation into small pieces in which the operating and equilibrium lines are locally straight.

A spreadsheet can tabulate the heavy key $y$ compositions stage-by-stage, the driving forces $(y–y^*)$ at the beginning and at the end of each stage, the log mean driving force over the stage, and the $NTU_{OG}$ for that stage. The sum of the $NTU_{OG}$ values of all the stages is the $NTU_{OG}$ of the column section.

Table 1 shows a simple rule that quickly converts theoretical stages to transfer units.

The database of low-relative-volatility packing tests can provide the $HTU_{OG}$ values for high-relative-volatility distillation. The characteristic low-relative-volatility *HETP* values are also more broadly applicable $HTU_{OG}$ values. Most high-relative-volatility distillation designs encounter flow conditions and physical properties that are well represented in the database, so the characteristic *HETP* is also the applicable $HTU_{OG}$.

***There are two ways to express the design of columns in high-relative-volatility systems.***

1. Restate the theoretical staging needs as transfer units (*NTU*) and apply a consistent and repeatable packing *HTU* to the number of transfer units. This approach isolates the true difficulty of separation from the true performance of the packing. The packing performance as *HTU* can be adjusted for influences such as distribution quality, but the adjustments do not need to correct an understated task, so the *HTU* value will appear to be a reasonable number.
2. Continue to use theoretical stages (*NTS*) and apply a relative volatility correction factor to the packing *HETP*. In Example 1, this approach would state the separation task as three theoretical stages and the packing *HETP* as (2.01 multiplier) × (15 in. standard *HETP*) = 30 in. This traditional approach understates the separation difficulty as *NTS*, so the adjusted device performance *HETP* seems inconsistent with packing test data and with other uses of the packing. Without the above calculations, a 30-in. *HETP* in the example is certainly not obvious.

***There are also two ways to determine the relative volatility effect:***

1. Use the molar composition profiles of an equilibrium stage model to calculate the transfer units in each stage, as described above. Once understood, this is generally not a lengthy task. Another option is to use the multiplier in Table 1.
2. Use a mathematically equivalent approach to compute "lambda" λ = *mG*/*L* on each stage and use the following relation of *NTS* and $NTU_{OG}$:

$$NTU_{OG} = NTS\ (\ln \lambda) / (\lambda – 1) \quad \textbf{(14)}$$

The correction can be applied to the *HETP* rather than the separation task:

$$HETP = HTU_{OG}\ (\ln \lambda) / (\lambda – 1) \quad \textbf{(15)}$$

In Example 1 and Figure 2, the value of $m$ is 0.125 and $L/G$ is 0.625, so λ is 0.20 and (ln λ)/(λ–1) is 2.01. Based on these values, the *NTU* is 6, the *HETP* is 30 in., and the bed depth is 90 in., just as previously calculated. Equilibrium stage simulations can be modified to calculate and tabulate values of λ and (ln λ) / (λ–1) automatically.

The effect of relative volatility on apparent packing efficiency as *HETP* is not new. The 1986 work of Koshy and Rukovena [5] applied λ correction factors to explain apparently poor packing *HETP* values in high-relative-volatility systems. The effect of relative volatility on packing *HETP* has

## HIGH-RELATIVE-VOLATILITY DISTILLATION (RECTIFICATION SECTION)

***Example 1:*** A column requires three stages of rectification, where the heavy key component diminishes by a factor of five on each stage, as in Figure 2. As implied by Table 1, the three stages are equal to about six transfer units ($NTU_{OG}$ = 6). A packing characteristic *HETP* value of 15 in. is also the $HTU_{OG}$ in conditions similar to the distillation tests. Therefore:

$$H = HTU_{OG} \times NTU_{OG} = 15 \times 6 = 90 \text{ in.}$$

This is the minimum packing depth for the column to provide the three theoretical stages. ❑

## NOMENCLATURE

| | |
|---|---|
| *a* | interfacial mass transfer area per volume of packed bed |
| *A* | surface area of heat exchanger |
| *G* | molar vapor rate in a column |
| *h* | elevation in packed bed |
| *H* | total packed bed Height |
| *HETP* | Height Equivalent to a Theoretical Plate |
| *HTU* | Height of a Transfer Unit |
| *K* | mass transfer coefficient, moles/time/area |
| *L* | molar liquid rate in a column |
| *LMTD* | log mean temperature difference between heat exchanger fluids |
| *m* | the slope of the equilibrium line |
| *NTS* | Number of Theoretical Stages (same as number of theoretical plates) |
| *NTU* | Number of Transfer Units |
| *S* | cross-sectional column area |
| *(T-t)* | temperature differential of two fluids across surface of a heat exchanger |
| *U* | exchanger overall heat transfer coefficient |
| $x$ | liquid molar composition within a column |
| $x^*$ | liquid molar composition that would be in equilibrium with the vapor |
| $x_1$ | liquid molar composition at the start of a theoretical stage |
| $x_2$ | liquid molar composition at the end of a theoretical stage |
| $X_1$ | liquid molar composition at the inlet to a column or packed bed |
| $X_2$ | liquid molar composition at the outlet to a column or packed bed |
| $y$ | vapor molar composition within column |
| $y^*$ | vapor molar composition that would be in equilibrium with the liquid |
| $y_1$ | vapor molar composition at the start of a theoretical stage |
| $y_2$ | vapor molar composition at the end of a theoretical stage |
| $Y_1$ | vapor molar composition at the inlet to a column or packed bed |
| $Y_2$ | vapor molar composition at the outlet to a column or packed bed |
| $\lambda$ | mG/L; the ratio of the slopes of operating and equilibrium lines |

become well known but is not well understood. Applying correction factors to the "packing performance" *HETP* does not clearly explain that equilibrium stages understate the separation difficulty, and the adjustment of apparent packing efficiency is trying to compensate for this understatement.

## ABSORPTION

Absorption processes are similar in some ways to rectification. But because the liquid phase is not limited to condensed vapor, there can be a wide range of liquid conditions. High liquid rate, high liquid viscosity, liquid-phase chemical reactions, limited solute solubility and extremes of "relative volatility" can affect mass transfer rates.

Few commercial absorbers contact vapor and liquid in near-equilibrium conditions. Most absorbers employ a solvent that exhibits little or no "backpressure," which is the equilibrium solute pressure over the partially loaded solvent; it indicates the tendency for absorbed solute to desorb back out of the solvent. So absorption can be similar to high-relative-volatility rectification in calculation of *NTU*.

Some absorbers employ solutions that have poor solubility for the solute, or they involve slow chemical reactions in the absorption process. Strigle [*6*] calls these columns "liquid-film-controlled" absorbers, and Equation (3) does not apply well. Sometimes the absorption rate is governed by a reaction rate rather than the mass transfer driver ($y$–$y^*$). Maybe the equilibrium composition $y^*$ is zero in theory, after a reaction is complete, but is not zero at the point of mass transfer because the reaction is slow. Or the slow pace of solute acceptance in the liquid alters the mass transfer coefficients so that the *HTU* values are not predictable constants.

The classic example of a liquid-film-controlled absorption is the absorption of $CO_2$ into weak caustic solution. The system is thought to be liquid-film-controlled because of the low solubility of $CO_2$ in water. The $CO_2$ molecules concentrate at the liquid surface, waiting for the solution to dissolve them as $CO_2$ before converting them to carbonate. Once the $CO_2$ is finally absorbed into the water, the caustic neutralizes it completely, thus giving the illusion of an excellent solvent with no back pressure.

This paper cannot address liquid-film-controlled absorbers, which evade broadly applicable design principles and require many individual approaches. However, most commercial absorption processes are not so complex. They involve simple mass transfer concepts wherein concentration driving forces cause mass transfer and the vapor-phase mass-transfer resistance controls the absorption rate. Designs do not involve reaction rate or liquid film control. As with high-relative-volatility distillation, theoretical stages understate the mass transfer task, but transfer units accurately express the task.

In many cases, an equilibrium stage simulation can establish mass and heat balances, compute the equilibrium relationship, and establish operating and equilibrium curves by dividing the overall absorption into smaller pieces. The $NTU_{OG}$ can be calculated for each stage, as described in the high-relative-volatility discussion.

The extreme theoretical stage dilemma occurs in systems with zero back pressure. The absorption of strong water-soluble acid vapors by caustic is an example. The acid reacts quickly and irreversibly with the caustic, and the still-alkaline solution has zero acid volatility. Because one theoretical stage is exactly 100% absorption, all such columns represent slightly less than one theoretical stage. This can create the illusion of a very easy absorption and a very short column. It can also create the illusion of high product purity, with 0.0 ppm of acid remaining in the vapor. For these reasons, an equilibrium stage simulation is ineffective for mass transfer design.

The extreme case of zero back pressure has a simple resolution. With no back pressure, $y^*$ is identically zero, and the definition of $NTU_{OG}$ in Equation (7) simplifies to:

$$NTU_{OG} = \int_{Y_1}^{Y_2} \frac{-dy}{(y - y^*)} = \int_{Y_1}^{Y_2} \frac{-dy}{y} = \ln \frac{Y_1}{Y_2} \qquad (16)$$

This is the common equation for "first-order decay." Someone could have defined "HHL" as height of a solute half-life, or "H90" as height for 90% solute removal. (Actually there is an old rule-of-thumb that a 10-ft bed of packing provides 90% removal, two beds provide 99% removal, and so forth.) Nuclear first-order decay has taught that 100.000% removal (one theoretical stage) is never attained.

In some absorbers, the solvent load near the bottom of the column has significant back pressure, so transfer units in the bottom of the column must be calculated stage by stage using Equation (13). After the vapor passes through a zone of loading solvent, it passes into a zone where the solvent is lean and has little back pressure, so the remainder of the transfer units can be calculated from Equation (16).

The wide variety of absorber flow conditions can make the prediction of $HTU_{OG}$ complex. Some absorbers have flow conditions similar to those of the packing low-relative-volatility tests, so the expected $HTU_{OG}$ values will be like those of the test data. Other absorbers have conditions that differ from the distillation tests, so the test $HTU_{OG}$ values need adjustment. These adjustments can include the following:

- Upward adjustment for high liquid viscosity
- Upward adjustment for poor packing wetting with aqueous solvent
- Upward adjustment if the intended liquid distributor is imperfect

A high liquid rate in absorption service improves the $HTU_{OG}$ value by creating much surface area for the relatively slow vapor to contact, so distillation $HTU_{OG}$ values can be too conservative at high $L/G$.

Some companies or industries have

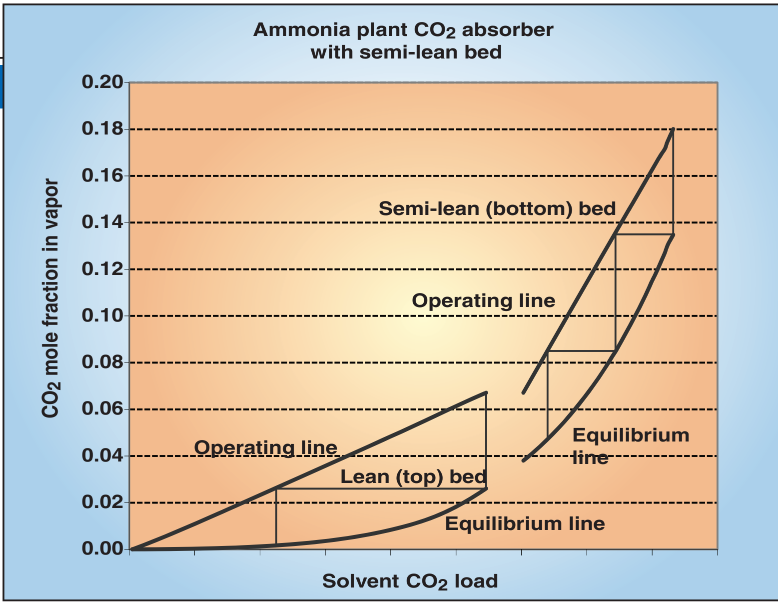


**FIGURE 3. A complex absorption can include a column zone of zero back pressure as well as zones of parallel and non-parallel equilibrium/operating lines**

## ABSORPTION

***Example 2:*** An absorber whose solution exhibits no solute back pressure starts with 1.5 mol% solute in the vapor, and needs to reach 10 ppmv. This absorber needs ln (15,000/10) = 7.3 transfer units. This is not a trivial task, even though it is "only one theoretical stage."

***Example 3:*** Figure 3 represents a $CO_2$ amine absorber with both lean and semi-lean beds of packing, and the very lean solvent has negligible back pressure. The absorber needs to reduce the gas from 18% (mole) to 100 ppmv $CO_2$. In the semi-lean (bottom) bed, the operating and equilibrium curves are roughly straight lines from stage to stage, and using log mean driving forces estimates this bed as 2.7 transfer units.

In the lean (top) bed, only the bottom stage has back pressure; this stage absorbs the $CO_2$ to 0.026 mole fraction. The log mean of the driving force over this stage implies it is 1.3 transfer units. Note that the equilibrium curve is bowed away from the operating line throughout the stage, so the average driving force is a little greater than the log mean, which is accurate for straight operating and equilibrium lines. Careful integration of *NTU* for the bottom stage implies 1.2 transfer units, if the added effort and accuracy is desired.

Above this stage, the solvent has near-zero back pressure, so the remainder of the column is about ln (26,000/100) = 5.6 transfer units from Equation (16). Therefore, the top bed is approximately 1.2 + 5.6 = 6.8 transfer units. ❑

packing efficiency data in various services. Measured $HTU_{OG}$ values are more applicable to other designs and columns than are *HETP* values. Because absorption *HETP* values contain corrections for poorly quantified mass transfer tasks, they are not useful in other columns unless they replicate the error too!

## LIQUID AND VAPOR FILM RESISTANCES

Discussion of liquid stripping will require considering the individual film resistances of vapor and liquid, and their relative contribution to overall mass transfer.

Two-film theory of mass transfer divides the mass transfer process into two resistances: the liquid phase resistance and the vapor phase resistance. It says that the phase interface resistance is negligible, so that equilibrium is reached at the interface. There is a concentration gradient of $x$ in the liquid phase, an equilibrium between $x$ and $y$ at the interface, and a concentration gradient of $y$ in the vapor phase. The concentration gradients can be expressed in terms of resistance to mass transfer in each phase.

*HTU* values can be broken into individual phase components:

$$HTU_{OG} = HTU_G + \lambda\, HTU_L \quad \textbf{(17)}$$

$$HTU_{OL} = HTU_L + (1/\lambda)\, HTU_G \quad \textbf{(18)}$$

Note that in the extreme of low-relative-volatility distillation, $\lambda = 1$ and

$$HETP = HTU_{OG} = HTU_{OL}$$
$$= HTU_G + HTU_L \quad \textbf{(19)}$$

In distillation, the value of $HTU_G$ is usually greater than $HTU_L$. This implies that the liquid phase spreads thinly over the packing, it turns over quickly, and it builds little gradient between the interface and the bulk liquid. The vapor phase, however, does not quickly saturate the interface, so there is a larger concentration gradient between the bulk vapor and the interface, and more packed height is needed for mass transfer.

The low-relative-volatility distillation database says more about $HTU_G$ values than $HTU_L$ values. The observation about consistent low-relative-volatility *HETP* values over various rates and systems must apply to $HTU_G$ values too, because $HTU_G$ is the largest component of *HETP*. But the consistency of low-relative-volatility *HETP* values does not necessarily apply to $HTU_L$ values. $HTU_L$ values could vary within the database with little effect on *HETP* values, because $HTU_L$ contributes little to *HETP*.

## HIGH-RELATIVE-VOLATILITY DISTILLATION — STRIPPING SECTION

The above high-relative-volatility distillation discussion focused on the rectification section only. The stripping section involves similar concepts and equations, but uncertainty over $HTU_L$ values makes calculations more uncertain.

Figure 4 illustrates one theoretical stage of the stripping section of a high-relative-volatility distillation. The driving force ($x$–$x^*$) is the horizontal distance between the equilibrium and operating lines. As in the rectification case, the driving force is large at the beginning of the stage, but it declines as mass transfer occurs and the liquid moves down the operating line.

As with $y$ values in rectification, the number of transfer units ($NTU_{OL}$) can be evaluated with $x$ compositions of the light key component as it is stripped from the liquid. Possible techniques include using an equilibrium stage simulation and a spreadsheet as described above, or using Table 1 again, or evaluating $\lambda$ on each stage and applying the $\lambda$ correction factor in Equation (20).

$$NTU_{OL} = NTS\, \lambda\, (\ln \lambda) / (\lambda - 1) \quad \textbf{(20)}$$

For high-relative-volatility rectification, direct application of *HETP* values from low-relative-volatility test data as high-relative-volatility $HTU_{OG}$ values was really a minor conservative approximation. A more exact approach is to use $HTU_G$ and $HTU_L$ values to recalculate $HTU_{OG}$ in Equation (17). The value of $HTU_{OG}$ will decline slightly, as $\lambda$ could decrease from near unity in low-relative-volatility rectification, to a value well below one for high-relative-volatility rectification. Because the individual $HTU_G$ and $HTU_L$ values are unknown, the exact

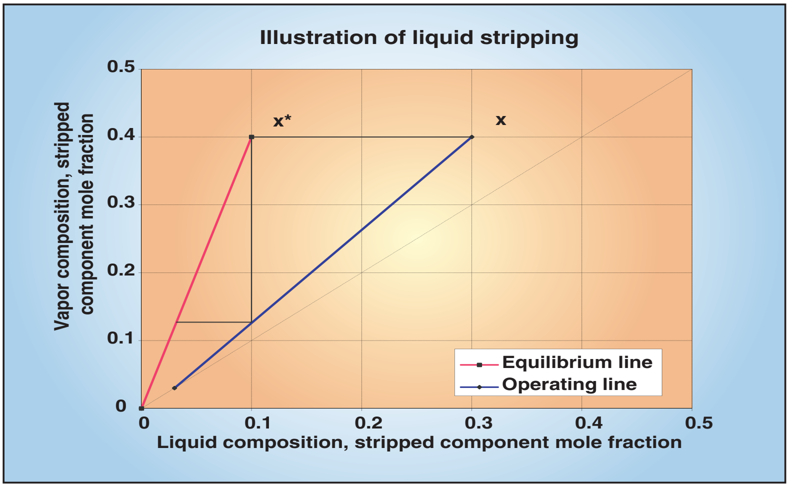


**FIGURE 4.** Liquid stripping can also exhibit rapid change of mass-transfer driving force over one theoretical stage

amount that $HTU_{OG}$ will decline is unknown. But the decline will be small because $HTU_G$ is larger than $HTU_L$.

The stripping section of high-relative-volatility distillation can similarly use the $HTU_G$ and $HTU_L$ values from low-relative-volatility distillation in Equation (18). In high-relative-volatility stripping, the λ value may increase from near unity to a value well above one. This decreases the value of $HTU_{OL}$ by decreasing the second term in Equation (18). Because the larger of the two terms is the one that declines, the magnitude of the decline of $HTU_{OL}$ is unknown; it may or may not be small. Using the *HETP* value from the low-relative-volatility distillation data as an approximate $HTU_{OL}$ value in high-relative-volatility stripping could be conservative. Koshy and Rukovena [*4*] illustrated this effect when they found that minimum *HETP* values do not occur at λ = 1, but at λ > 1.

In the above situation, an engineer could choose to use the low-relative-volatility *HETP* as a conservative $HTU_{OL}$ value, to avoid a difficult search for sources of $HTU_L$ or $HTU_{OL}$ data or $K_xa$ data.

## REBOILED LIQUID STRIPPING

In reboiled strippers, the liquid mixture is at its boiling point and the vapor is composed of the same components as the liquid. In most reboiled strippers, the flow conditions, physical properties, and equilibrium conditions are similar to those of the stripping section of a high-relative-volatility distillation column. Reboiled strippers can generally be addressed by the techniques and calculations of the "High-relative-volatility distillation — stripping section" discussion above.

## LIQUID STRIPPING WITH STEAM OR INERT GAS

As the above discussion moved from high-relative-volatility rectification to absorption, counting transfer units $NTU_{OG}$ stayed the same, but the variety of potential solvents presented challenges in finding $HTU_{OG}$ values. Similarly, for liquid stripping that is not reboiled in stripping of bubble point liquid, counting transfer units $NTU_{OL}$ stays the same, but there are problems finding the $HTU_{OL}$ value for the stripper.

In strippers that use steam or other light gas to strip light compounds from a liquid mixture, the liquid mixture is not at bubble point, so its viscosity can be high. Many such strippers operate with little stripping gas and with little solute stripped, so that *L/G* ratios can be very high, vapor rates can be very low, and liquid rates can be very high. The distillation data that suggested *HTU* values in other columns are not helpful in suggesting $HTU_{OL}$ values under these conditions.

This article does not have approximations of $HTU_{OL}$ for the wide variety of strippers represented in this category of mass transfer. However, high volatility and few stages are not indicators of a trivial task, and an accurate $NTU_{OL}$ count and a reasonable $HTU_{OL}$ approximation are needed. A 2007 paper by Lopez-Toledo [7] and others at The Dow Chemical Co. presents a general correlation for $k_L$ values that can be used to build $HTU_{OL}$ for stripping service.

If a stripping column is large and a conservative approximation is too expensive, the situation could justify research and testing to measure $HTU_{OL}$ values. This situation occurred several years ago when an entire industry needed design data for stripping VOC (volatile organic compounds) from contaminated groundwater. The magnitude of the need justified many packing tests.

## DISTILLATION TRAYS

This article has not addressed trays, as opposed to packing, as the mass transfer device. However, nothing in the analysis of driving forces and nothing in the counting of transfer units is specific to the type of mass transfer device. As with packing, equilibrium stages are a poor representation of the mass transfer task of trays, and tray efficiencies must account for this. For that reason, trays with good bubbling activity and tall weirs can exhibit tray efficiencies of 25% in absorption service. The 1946 O'Connell [8] tray efficiency correlation has a relative volatility effect, because high relative volatility implies low "apparently poor" tray efficiency.

There may be a perception difference between packing and trays, in that 25% tray efficiency in absorption service is not perceived to indicate poor performance of the tray, but a packing HETP of 2,000 mm is often perceived as poor performance. Designers may accept without question the premise that 12 trays are needed for one or two absorption stages, or 20 trays for three absorption stages. An understanding of transfer units will help explain tray efficiency under high-relative-volatility and absorption conditions. ■

*Edited by Rebekkah Marshall*

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Electro Static Technology

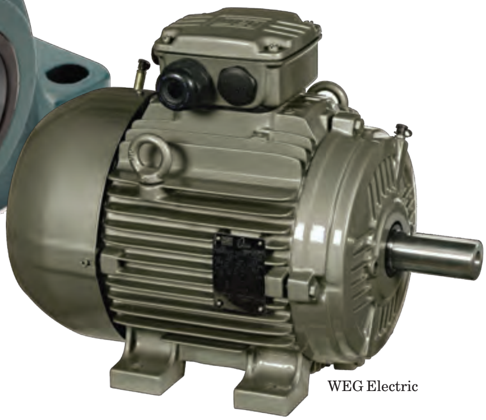

**FOCUS ON**

# Motors & Drives

### Safely ground shaft currents to protect bearings

The Split-Ring Aegis bearing-protection ring with conductive epoxy mounting (photo) can protect a.c. motor bearings from electrical damage by safely grounding shaft currents induced by variable frequency drives. The protection ring can be installed quickly without detaching coupled equipment, and prevents bearing noise, downtime and motor repairs. — *Electro Static Technology, Mechanic Falls, Maine*
**www.est-aegis.com**

Baldor Electric



WEG Electric

### Load ratings for these bearings are the highest around

Type E-Xtra bearings (photo) have the highest load ratings in the industry, this company says, and also feature an advanced sealing system. Manufactured in the U.S., the high-capacity tapered roller bearing insert allows for a combination of radial and thrust loads, yielding the highest available load ratings. According to the company's laboratory tests, the new tapered insert has load ratings 13–14% higher than previously existing inserts. The carburized inner ring has also been designed to absorb shock and resist cracking. Type E-Xtra bearings feature the exclusive XTS triple-lip seal, an advanced system that protects against contamination in dusty or wet environments. The bearings are pre-assembled, prelubricated and factory-adjusted for easy installation. — *Baldor Electric Co., Fort Smith, Ark.*
**www.baldor.com**

### Permanent-magnet motors reduce size and weight

The WMagnet Series (photo) is a permanent-magnet motor designed for mainstream usage. The high-efficiency WMagnet motors reduce size by up to 50%, and weight by up to 36%, with efficiencies up to 97.5% compared to equivalent size-induction motors. WMagnet motors are designed for applications where constant torque, low vibration and low noise are required. The series is manufactured with high-energy neodymium-iron-boron (NdFeB) magnets in their rotors. — *WEG Electric Corp. U.S., Duluth, Ga.*
**www.weg.net/us**

### A reversing drive with minimal strain

The dual-clutch system on this high-speed reversing drive allows for rapid reversing without undue strain on the motor or drive system. In traditional reversing applications, motors must accelerate in the forward direction, stop, then accelerate in the opposite direction before stopping again. With the dual-clutch system, known as Posidyne, the inputs to the two clutches rotate in opposite directions. One motor, rotating in the forward direction, is connected through a primary clutch, and a second motor in the reverse direction, is connected through a secondary clutch. By actuating the proper clutch and brake, the reversing is handled within the Posidyne, while the motor runs continuously. The High-Speed Reversing Drives are ideal for higher horsepower (up to 75 hp) applications that require frequent reversing, such as mineral processing, machine tools, loading machines and more. — *Force Control Industries, Fairfield, Ohio*
**www.forcecontrol.com**

### These motors are designed for high temperatures

This motor is designed to handle demanding applications where ambient temperatures are high (up to 90°C). Suitable for applications where high temperatures are crucial, such as in the metallurgical, wood and food in-

Siemens

dustries, the motor is harmonized for IEC – Cenelec power and frame-size standards. The motor's output power ranges from 11 to 55 kW, and it is available with a moisture ingress protection rating of 55. It can handle all common voltages. — *ABB Ltd., Zürich, Switzerland*
**www.abb.com**

**Explosion-proof motors are used in these blowers**

The motors in these regenerative blowers are UL- and CSA-approved for use in Class 1, Group D explosive gas environments. Typical applications include landfill gas recovery, scrubbing, vent-header off-gassing and others. The explosion-proof motors found in Rotron EN and CP blowers can accommodate international voltage and frequency requirements, and can deliver horsepower to meet the requirements of the most demanding applications. — *Ametek Technical and Industrial Products, Kent, Ohio*
**www.ametektechnicalproducts.com**

**These monitoring relays protect motors**

Monitoring relays from this company have all been equipped with IO-Link, a communication standard designed for uniformly linking sensors and switching devices to the control level via a cost-effective, point-to-point connection (photo). The monitoring relays are key to reliably protecting motors by monitoring parameters such as temperature, speed, network quality, current and voltage. As an open interface, IO-Link can be integrated into all conventional fieldbus and automation systems. — *Siemans AG, Industry Automation Div., Erlangen, Germany*
**www.siemans.com**

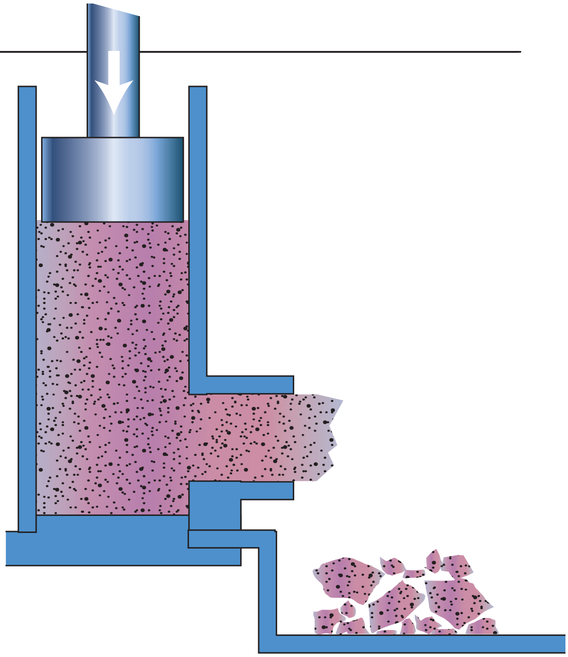
**These motor gearboxes are ideal for OEM applications**

This company's planetary gearboxes are ideal for proprietary OEM use and as replacements for conventional gearboxes. They are 90% efficient and can be half the size of conventional gear units, allowing them to save weight by 60% and fit into spaces where others will not. — *Brevini Power Transmission, Reggio, Italy* ■

*Scott Jenkins*

# Characterizing Powder Flow

**Flow behavior is influenced by prevailing process conditions. Efforts to assess powder characteristics must be aligned with the process itself**



**Tim Freeman**
Freeman Technology Ltd.

To confidently design, operate and troubleshoot solids-handling processes, engineers need to characterize powder flow in ways that relate to in-plant behavior. Universal powder testers provide the multi-faceted characterization that is necessary to reliably predict operational performance. This article examines the data that such instruments generate, and discusses their practical application.

While many process engineers would express confidence in their ability to effectively design and optimize plants for liquid and gas processing, even those with extensive experience are often challenged by powder-handling processes. The open literature offers only limited data and the links between actual process behavior and defined powder properties often appear tenuous and complex. However, for effective processing and design, it is essential to describe powder behavior in a process relevant way.

Dynamic flow characterization measures powders in motion, offering engineers an intuitively rational approach to characterization. The most advanced dynamic powder testers incorporate a range of methodologies, characterizing conventional bulk and shear properties to supplement dynamic measurement. Since powders can be measured in a consolidated, conditioned, aerated or even fluidized state, these universal powder testers generate information that relates closely to a wide range of processing conditions. Such data provide a firmer basis for design, and provide insight that rationalizes operational experience, enhancing the underlying knowledge base.

One of the most important aspects of powder behavior is flowability under real-world conditions. Getting a powder to flow smoothly through multiple unit operations, at the required flowrate, is often extremely difficult. Here we consider why powders exhibit variability, and addresses the issue of powder flow in some detail. A particular focus is the impact of applied force, the contrast between extruded or forced versus unconfined flow, and the implications of these for processing.

## Powder fundamentals

Key to understanding powders is an appreciation of the reasons why behavior, especially flow properties, can change so radically under process plant conditions. Unfortunately many variables influence flowability. Some relate to the solid itself — particle size, shape, surface roughness or density, for example — while others are determined by the processing environment or system.

Primary examples of system variables include air content, electrostatic charge and moisture level. Maintaining consistency, during both measurement and processing is challenging, because it requires that all influential variables be kept constant (or at least controlled within limits).

Over time, the flow behavior of a powder that starts off its processing life with well-defined flow characteristics may change. For instance, as it passes through the plant, the powder may pick up or lose moisture, becoming tribo-charged or segregated, suffer from attrition or agglomeration (thereby changing size and/or shape), fluidize or become compacted. Each change will influence flowability.

This is why it is so important to understand the conditions to which the powder will be exposed as it moves through different unit operations. For example, during transport, powders may consolidate through vibration, while those in bulk storage in a silo, sack or hopper may consolidate under their own weight. Conversely, discharge from a container or sack usually increases aeration, which encourages the powder to flow freely — possibly too freely — potentially increasing the risk of flooding. If the moisture level of the storage or transport environment is not closely controlled, then this too is likely to influence downstream processing performance.

Knowing what demands the process is going to place on the powder is, however, only one side of the problem. The other is understanding the powder's likely response. This is where the use

**FIGURE 1. Using a powder rheometer to investigate the extrusion behavior of powders, a downward force on the piston pushes material out of the orifice on the right hand side. Extrusion is stopped when a force limit is reached**

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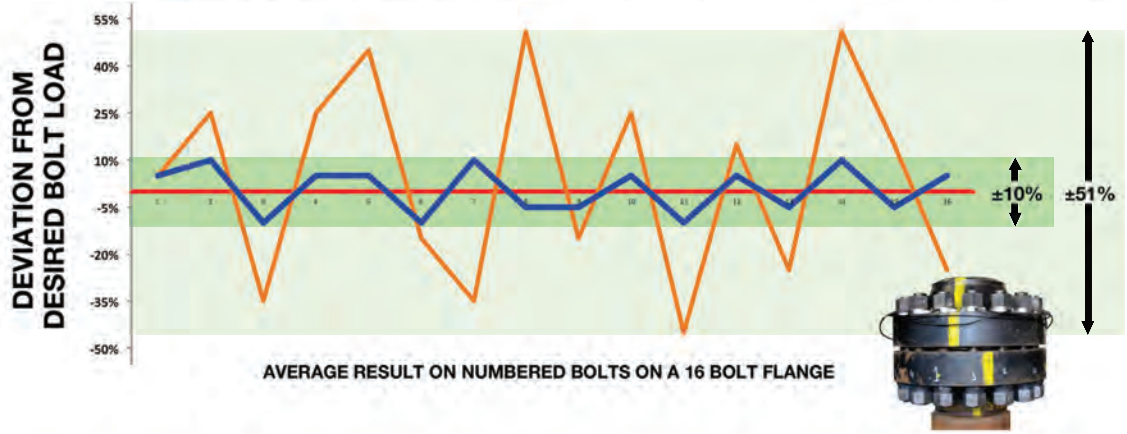


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of relevant measurement techniques plays an important role. Matching powder properties with the demands of the process is essential to robust, trouble-free operation. In contrast, a poor match will give rise to the problems that are routinely encountered by solids processors: variable flowrates, stoppages/blockages, sub-optimal finished product quality and excessively high manual-input requirements.

## Measuring powders

Over the decades, in an effort to produce tools that aid understanding, powder scientists and engineers have developed many different characterization techniques. Bulk, shear and dynamic properties are all now commonly used as input to the design and operating strategies, with universal powder testers incorporating all three types of measurement in a single instrument. Important bulk properties include density, compressibility and permeability, while shear properties define both the ability of a consolidated powder to transition from a stationary into a dynamic state, and the ease with which it will move against the surface of the process equipment. Dynamic properties relate directly to flowability, since they are measures of a powder in motion, and quantify cohesion as well as sensitivity to such influencing factors as aeration, consolidation, flowrate, moisture and electrostatic charge.

Core dynamic parameters, such as basic flowability energy (BFE) and specific energy (SE), quantify how easily a conditioned powder moves when it is subjected to compacting motion, and when disturbed in an unconfined way, respectively. By characterizing samples in a compacted, aerated or even fluidized state, the effect of air on the baseline BFE measurement, and hence on flow behavior, can be readily quantified. The effect of other variables such as flowrate and moisture content is equally easy to evaluate.

Conditioning the sample prior to measurement is an important preparation step, involving closely prescribed, gentle displacement of the powder. Excess air is released from an overly aerated bed, while a consolidated sample is broken up. The goal in either case is to achieve a homogeneous, loosely packed, slightly aerated powder bed. This conditioning step ensures high reproducibility, which supports the sensitivity of dynamic characterization. Techniques that fail to employ such a preparation step are likely to provide results that are a function of the way the powder was handled and loaded by the operator, as much as they reflect true differences between test samples.

The following case study highlights the type of information that can be generated using a universal powder tester, focusing on the contrast between forced and unconfined flow behavior. As the results illustrate, powders that flow freely when unconfined can "lock up" and exert high resistance to forced flow, while more cohesive materials, which flow poorly under gravity, extrude when forced to flow.

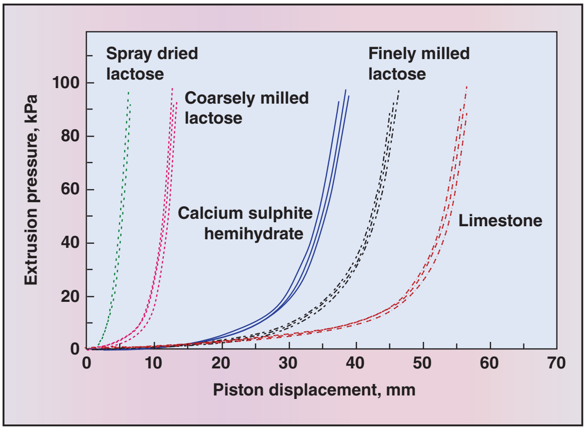



**FIGURE 2.** **This figure shows the extrusion pressure as a function of piston displacement for five different powders (at piston velocity of 10 mm/s). As the piston pushes down on the powder extrusion, pressure rises to an imposed limit at which point extrusion is stopped**

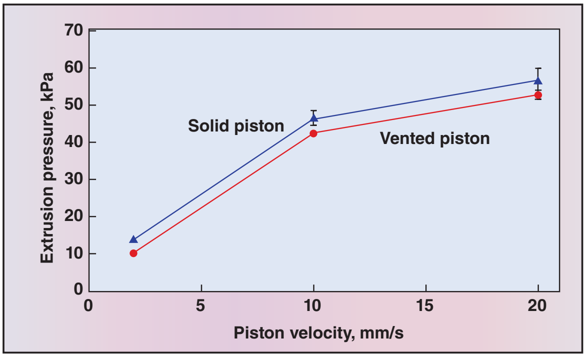



**FIGURE 3.** **This figure shows the influence of piston type and extrusion speed on the extrusion performance of limestone powder. Faster extrusion speeds are more efficient, but the type of piston used has little impact**

## Case study

***Investigating the extrusion behavior of different powders.*** Physical and flow properties (dynamic, bulk and shear) were measured for five different materials: limestone (CRM116), three grades of lactose (spray dried, coarsely milled and finely milled) and calcium sulphite hemihydrate. A universal powder tester was used, employing standard methodologies for all flow measurements [*1, 2, 3*]. Fitting the instrument with an extrusion device also enabled the extrusion behavior of the powders to be studied (Figure 1).

During extrusion tests, a piston forces a conditioned sample of known volume through a 25-mm bore cylinder and out of an 18-mm diameter orifice. During the test, the compressing piston moves down at constant speed until a force limit is reached, at which point the amount of extruded powder is weighed to determine an extrusion percentage: the mass of extruded material compared to the initial mass of powder in the cylinder. Compression tests were carried out using a vented piston, which allows air to escape through the piston face, and the results were compared to data

| **TABLE 1. SAMPLE PHYSICAL PROPERTIES, FLOW PROPERTIES AND EXTRUSION PERFORMANCE DATA** | | | | | |
|---|---|---|---|---|---|
| **Measurements:** | **CRM116 limestone** | **Finely milled lactose** | **Calcium sulfite** | **Spray dried lactose** | **Coarsely milled lactose** |
| $d_{50}$ particle size, mm | 4 | 20 | 7 | 130 | 100 |
| Particle/granular shape | angular | angular | angular | spherical | angular |
| Conditioned bulk density (CBD), g/ml | 0.74 | 0.46 | 0.57 | 0.64 | 0.75 |
| Basic flowability energy (BFE), mJ | 576 | 635 | 878 | 1191 | 2164 |
| Flowrate index (FRI) | 2.06 | 1.86 | 1.73 | 1.05 | 1.12 |
| Specific energy (SE), mJ/g | 7.9 | 9.6 | 9.6 | 4.8 | 7.1 |
| Aeration ratio (AR; as BFE/energy at 14 mm/s) | 1.6 | 3.5 | 3.7 | 156 | 149 |
| Bulk density after consolidating with 100 taps, g/mL | 0.95 | 0.66 | 0.80 | 0.74 | 0.90 |
| Consolidation Index, $CI_{100Taps}$ (a factor by which flow energy increases after tapping, relative to the BFE) | 3.3 | 7.9 | 5.7 | 3.4 | 4.0 |
| Compressibility, % (Volume change under 18kPa direct pressure) | 27.1 | 29.2 | 29.0 | 4.6 | 8.5 |
| Permeability (as pressure drop across the powder bed at 11kPa normal stress and 2 mm/s air velocity, $PD_{11}$) mbar | 43.2 | 16.7 | 21.5 | 0.7 | 1.5 |
| Unconfined yield strength ($t_c$), kPa | 2.50 | 3.58 | 3.23 | 0.38 | 0.80 |
| Cohesion ($t_0$), Pa | 656 | 852 | 749 | 121 | 239 |
| Flow function (FF) | 6.0 | 4.2 | 4.7 | 32.6 | 16.8 |
| Generated normal stress/shear stress * | 0.45 | 0.53 | 0.75 | 1.2 | 0.90 |
| Extrusion percentage at 10 mm/s piston speed, % | 46.3 | 25.8 | 15.2 | 2.9 | 3.5 |

*Definition shown in Reference 3

obtained during compression with a solid piston. Compression speed was also investigated by varying the axial speed of the piston.

A comparison of the extrusion results for the different materials shows markedly differentiated behavior. The limestone extrudes relatively easily, with almost half of the material extruding from the orifice before the force limit is reached. By comparison, the coarsely milled and spray-dried lactose (which have an extrusion percentage of 3.5 and 2.9%, respectively) extrude far less easily. Plotting the pressure rise observed during extrusion (Figure 2) shows that for the limestone, pressure increases relatively slowly, rising more rapidly only when the piston starts to obstruct the outlet to the orifice (Figure 1). Conversely, with less easily extruded materials, the piston travels a much shorter distance before reaching the force limit.

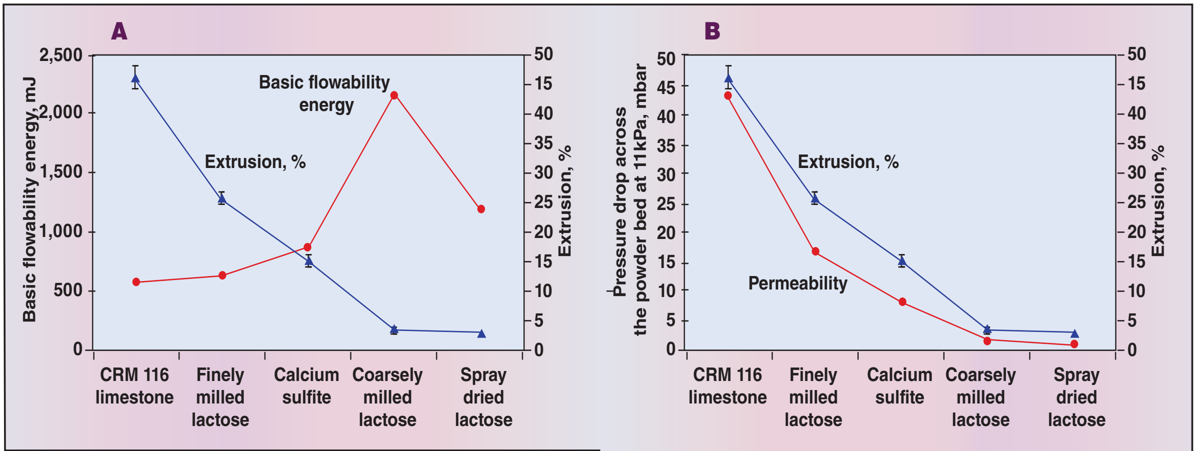
Figure 3 illustrates the effect of extrusion speed and piston type for limestone. As shown, extrusion is more successful when the piston moves at higher rates, thereby reducing the time available for the entrained air to escape under compression. By contrast, the type of piston used has less of an effect.

Extrusion behavior correlates particularly well with BFE, permeability and the ratio of generated normal stress to shear stress (Figure 4). This provides some insight into observed behavior. The relatively low permeability of the limestone highlights its reluctance to release air, a common feature of more cohesive materials. Powder beds containing larger or more spherical particles, such as the two coarse lactose grades for example, present little resistance to air flow. Finer particles on the other hand tend to form agglomerates that entrain air, retaining it within the sample.

The measurement of BFE subjects the powder to a compacting downward force, so it is closely akin to extrusion testing. As the blade pushes through the limestone sample the entrained air acts as a cushion, minimizing the flow zone and the forces acting on the blade. In contrast, pushing the blade through a coarsely milled lactose bed is much more difficult. Since there is little air present, the force transmits rapidly through the bed to the blade, the flow zone expands and the resulting BFE measurement is high (Figure 5). This is exactly analogous to the extrusion pressure profiles. With coarse materials, the compressing force transmits through the entire bed, which behaves more like a continuous solid, locking up and exerting significant resistance. With finer materials, the entrained air dampens this effect and lubricates the flow.

The anomalous BFE result for spray-dried lactose is attributed to the spherical nature of the particles, which helps to reduce flow energy, in comparison to the coarsely milled lactose with its irregular morphology. However, the ability of the regular spherical particles to lock up and resist flow when more closely confined is reflected in the ratio of normal stress to shear stress.

This parameter, which broadly



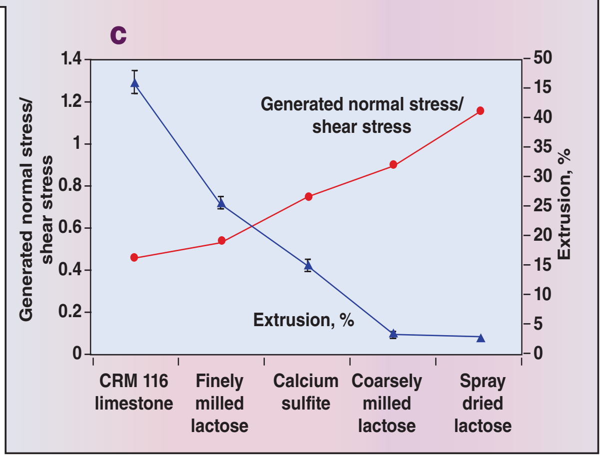




**FIGURE 4. This figure shows the correlation between powder extrusion performance and powder flow characteristics. Extrusion performance correlates directly with permeability, and is inversely related to both BFE and the ratio of generated normal stress to shear stress**

echoes the trends in BFE and extrusion percentage, is governed by the efficiency with which particles pack together. When particles are sheared in a horizontal plane, stresses radiate in all directions.

The result is a tendency for the powder to dilate, as particles need to move upward in order to move relative to one another in the horizontal plane. When particles are efficiently packed together, the stresses generated axially are relatively high, for the same reasons explained previously in relation to a high BFE: there are relatively few air spaces to accommodate the dilation. The relatively low shear stresses between the larger particles is further explanation for the larger generated ratio of normal stress to shear stress.

In this study, lower extrusion rates resulted in a smaller extrusion percentage, regardless of piston type. This is because a slower piston speed forces entrained air from the sample, making it more resistant to flow. This is supported by the flow rate index (FRI), which shows that the limestone is 2.06 times less likely to flow at low flowrates. The irrelevance of piston type confirms that it is the rate of air released from the bed via the extrusion orifice, rather than through the piston face, that controls this effect. Rapid extrusion encourages the retention of entrained air, maximizing the extrusion percentage. It is likely that the extrusion percentage for powders with lower FRI values would be less sensitive to piston speed.

## Optimization efforts

Characterizing powders as described above clearly generates a database of information; however, it also raises the question of how best to use the results for process optimization. One approach is to analyze the demands of the process and see whether the powder has properties that are a "good fit." Consider the process of tablet manufacture, where powder is required to flow efficiently under gravity into the die, and then demonstrate sufficient bulk stiffness to compress efficiently into a tablet.

Powders with a high extrusion percentage are likely to contain excess air and result in fill weight variability. When compressed, the low bulk stiffness means the punch will have to travel further to achieve the same compaction force, creating some tablets that are undersized. Conversely, powders that lock up and resist extrusion are likely to compact uniformly under the extreme stresses imposed, resulting in tablets with good mechanical strength and consistent size and dissolution characteristics. Powders with high values of BFE and permeability, and low values of SE and compressibility are therefore likely to be more consistent during tablet manufacture, resulting in tablets with the desired properties.

When the focus is on using an existing piece of equipment for a new material or troubleshooting an operation, efforts to develop a comprehensive characterization can leverage operational experience in a way that improves operations. Consider, for example, a screw feeder that is used to convey material from one point in the process to another, at a facility that handles a range of powders. With some products the equipment works well but with others it does not and a

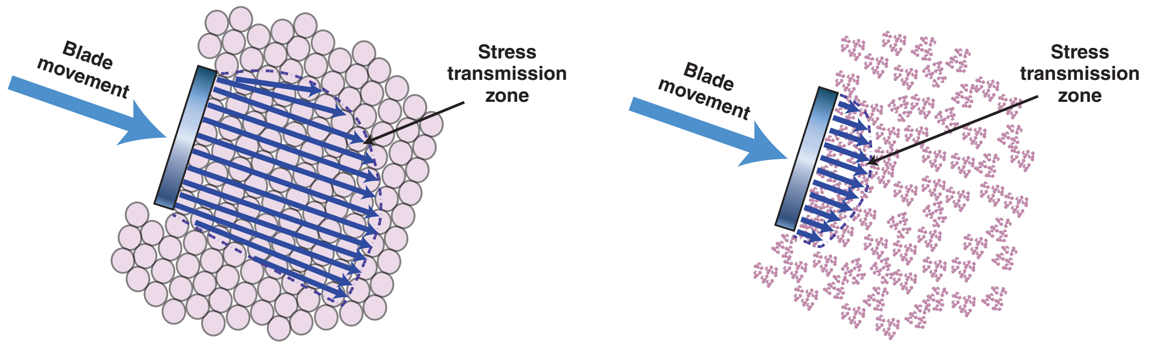



**FIGURE 5. In forced flow behavior of non-cohesive and cohesive powders, entrained air in the cohesive sample absorbs the motion of the blade, but with a closely packed powder the stress transmission zone is much larger, giving higher values of BFE**

poorly performing material is only detected once it is in the conveyor.

Here, comparing the properties of materials that are easily conveyed with those that are not leads to the definition of a specification for optimal operation. Instead of simply knowing that powder A performs poorly while powder B is fine, it becomes clear that establishing threshold values — for instance, BFE in the range $a$ to $b$ or permeability below $x$ — will help to define acceptability. In this way, if a new material is introduced, operational performance can be predicted before it goes into the plant. If there is no choice but to process a material that does not suit the equipment, then informed modifications can be made to process settings on the basis of understanding behavior.

This latter approach of rationalizing operational experience in terms of reproducibly measurable parameters is a powerful way of deriving maximum benefit from information that already exists within the company. Experience is, by its nature, empirical and specific. On the other hand, an understanding of what gives rise to certain types of behavior is knowledge that is more generic and widely applicable, and therefore has great value.

Comparing powder properties is especially effective for addressing batch-to-batch variability, in a feed for instance. Consider the case in which a material is sourced from two different suppliers. Both meet the defined specification, but detailed process monitoring shows that flow from the feed hopper is much more erratic with one material compared to the other. In this case the specification is not controlling a variable relevant to performance. However, measuring a range of parameters for both materials is likely to identify a difference. A particular powder's response to air or its propensity to segregate could influence in-hopper behavior. Defining the initial specification more closely on the basis of in-depth characterization eliminates the problem and provides a blueprint for alternative supplies.

## Closing thoughts

Powder processing is undoubtedly a challenge, but modern universal powder testers can help. They provide comprehensive characterization of a range of dynamic, bulk and shear properties. Dynamic measurements of a conditioned, compacted, aerated or fluidized sample in motion are especially relevant for processing applications and provide an intuitively sensible approach for process engineers. Such tests provide a sensitive, reproducible and reliable method of quantifying powder flowability and also measure the impact of variables such as air content, degree of compaction and flowrate. ■

*Edited by Suzanne Shelley*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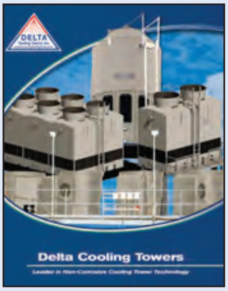


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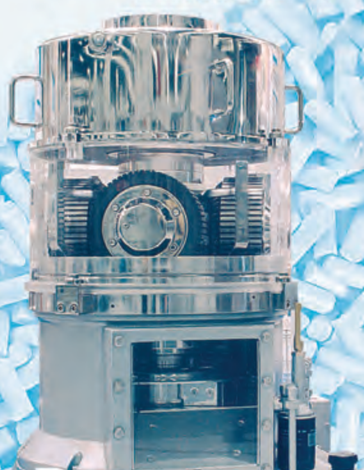

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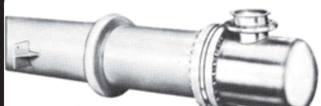

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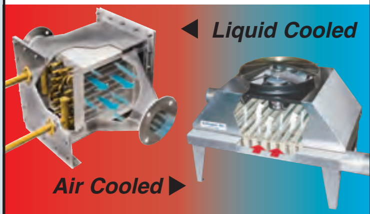


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## FREE PRODUCT INFO
***(please answer all the questions)***

### YOUR INDUSTRY
01 Food & Beverages
02 Wood, Pulp & Paper
03 Inorganic Chemicals
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 |
| 2 | 17 | 32 | 47 | 62 | 77 | 92 | 107 | 122 | 137 | 152 | 167 | 182 | 197 | 212 | 227 | 242 | 257 | 272 | 287 | 302 | 317 | 332 | 347 | 362 | 377 | 392 | 407 | 422 | 437 | 452 | 467 | 482 | 497 | 512 | 527 | 542 | 557 | 572 | 587 |
| 3 | 18 | 33 | 48 | 63 | 78 | 93 | 108 | 123 | 138 | 153 | 168 | 183 | 198 | 213 | 228 | 243 | 258 | 273 | 288 | 303 | 318 | 333 | 348 | 363 | 378 | 393 | 408 | 423 | 438 | 453 | 468 | 483 | 498 | 513 | 528 | 543 | 558 | 573 | 588 |
| 4 | 19 | 34 | 49 | 64 | 79 | 94 | 109 | 124 | 139 | 154 | 169 | 184 | 199 | 214 | 229 | 244 | 259 | 274 | 289 | 304 | 319 | 334 | 349 | 364 | 379 | 394 | 409 | 424 | 439 | 454 | 469 | 484 | 499 | 514 | 529 | 544 | 559 | 574 | 589 |
| 5 | 20 | 35 | 50 | 65 | 80 | 95 | 110 | 125 | 140 | 155 | 170 | 185 | 200 | 215 | 230 | 245 | 260 | 275 | 290 | 305 | 320 | 335 | 350 | 365 | 380 | 395 | 410 | 425 | 440 | 455 | 470 | 485 | 500 | 515 | 530 | 545 | 560 | 575 | 590 |
| 6 | 21 | 36 | 51 | 66 | 81 | 96 | 111 | 126 | 141 | 156 | 171 | 186 | 201 | 216 | 231 | 246 | 261 | 276 | 291 | 306 | 321 | 336 | 351 | 366 | 381 | 396 | 411 | 426 | 441 | 456 | 471 | 486 | 501 | 516 | 531 | 546 | 561 | 576 | 591 |
| 7 | 22 | 37 | 52 | 67 | 82 | 97 | 112 | 127 | 142 | 157 | 172 | 187 | 202 | 217 | 232 | 247 | 262 | 277 | 292 | 307 | 322 | 337 | 352 | 367 | 382 | 397 | 412 | 427 | 442 | 457 | 472 | 487 | 502 | 517 | 532 | 547 | 562 | 577 | 592 |
| 8 | 23 | 38 | 53 | 68 | 83 | 98 | 113 | 128 | 143 | 158 | 173 | 188 | 203 | 218 | 233 | 248 | 263 | 278 | 293 | 308 | 323 | 338 | 353 | 368 | 383 | 398 | 413 | 428 | 443 | 458 | 473 | 488 | 503 | 518 | 533 | 548 | 563 | 578 | 593 |
| 9 | 24 | 39 | 54 | 69 | 84 | 99 | 114 | 129 | 144 | 159 | 174 | 189 | 204 | 219 | 234 | 249 | 264 | 279 | 294 | 309 | 324 | 339 | 354 | 369 | 384 | 399 | 414 | 429 | 444 | 459 | 474 | 489 | 504 | 519 | 534 | 549 | 564 | 579 | 594 |
| 10 | 25 | 40 | 55 | 70 | 85 | 100 | 115 | 130 | 145 | 160 | 175 | 190 | 205 | 220 | 235 | 250 | 265 | 280 | 295 | 310 | 325 | 340 | 355 | 370 | 385 | 400 | 415 | 430 | 445 | 460 | 475 | 490 | 505 | 520 | 535 | 550 | 565 | 580 | 595 |
| 11 | 26 | 41 | 56 | 71 | 86 | 101 | 116 | 131 | 146 | 161 | 176 | 191 | 206 | 221 | 236 | 251 | 266 | 281 | 296 | 311 | 326 | 341 | 356 | 371 | 386 | 401 | 416 | 431 | 446 | 461 | 476 | 491 | 506 | 521 | 536 | 551 | 566 | 581 | 596 |
| 12 | 27 | 42 | 57 | 72 | 87 | 102 | 117 | 132 | 147 | 162 | 177 | 192 | 207 | 222 | 237 | 252 | 267 | 282 | 297 | 312 | 327 | 342 | 357 | 372 | 387 | 402 | 417 | 432 | 447 | 462 | 477 | 492 | 507 | 522 | 537 | 552 | 567 | 582 | 597 |
| 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 |
| 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 | 255 | 270 | 285 | 300 | 315 | 330 | 345 | 360 | 375 | 390 | 405 | 420 | 435 | 450 | 465 | 480 | 495 | 510 | 525 | 540 | 555 | 570 | 585 | 600 |

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# BUSINESS NEWS

## PLANT WATCH

**Ineos Technologies licenses its technology for a PP plant in China**

September 1, 2011 — Ineos Technologies (www.ineos.com) has licensed its Innovene PP (polypropylene) Process for the manufacture of homopolymers, random copolymers and impact copolymers to the Shaanxi Yanchang Petroleum Yanan Energy and Chemical Co. in Shaanxi, China. The 300,000-ton/yr Innovene PP plant will produce a wide range of products to serve the growing demand in China.

**UOP breaks ground on biomass-to-fuels facility in Hawaii**

August 30, 2011 — UOP LLC (Des Plaines, Ill; www.uop.com), a Honeywell company, has begun construction in Hawaii of a biofuels demonstration unit that will convert forest residuals, algae and other cellulosic biomass into "green" transportation fuels. Backed by a $25-million U.S. Dept. of Energy award, the UOP integrated biorefinery will upgrade biomass into high-quality renewable gasoline, diesel and jet fuel. Located at the Tesoro Corp. refinery in Kapolei, the integrated biorefinery will be used to demonstrate viability of the technology, test the fuels produced and evaluate the environmental footprint of the fuels and the process technology. The project is scheduled to begin initial production in 2012 and be fully operational by 2014.

**Evonik Industries will increase its methyl methacrylate production**

August 25, 2011 — Evonik Industries AG (Essen; www.evonik.com) is increasing the production capabilities of its methyl methacrylate plants through debottlenecking and plant expansion projects in its existing plants in Europe (Worms and Wesseling in Germany), Asia (Shanghai in China), and the U.S. (Fortier) in 2011 and 2012. Upon completion of the projects Evonik industries will be able to produce approximately 50,000 additional metric tons (m.t.) of methyl methacrylate, which is primarily used for polymethylmethacrylate resins and surface coatings.

**KBR provides construction services for rubber-plant expansion in Texas**

August 24, 2011 — KBR (Houston; www.kbr.com) was awarded a contract by Zeon Chemicals (Zeon; Louisville, Ky.; www.zeonchemicals.com) to provide construction services for Zeon's nitrile-rubber plant-expansion project in Pasadena, Tex. KBR will manage the first phase of Zeon's expansion plan, which will enable the plant to increase production of Zetpol hydrogenated nitrile rubber by 25%.

**BASF to invest in a world-scale acrylic acid complex in Brazil**

August 19, 2011 — BASF SE (Ludwigshafen, Germany; www.basf.com) will invest in a production site for acrylic acid, butyl acrylate and superabsorbent polymers (SAP) in Camaçari, Bahia, Brazil. This will be the first acrylic-acid and superabsorbents site in South America. With an investment of more than €500 million, it is the largest investment in BASF's century-long history in South America. In addition, BASF will start to produce 2-ethyl-hexyl acrylate, an important raw material for the adhesives and special coatings industries, in its existing chemical complex in Guaratinguetá, São Paulo. The construction of the new acrylic acid complex will start in 2011, and production is expected to begin in the 4th Q of 2014. The production for 2-ethyl-hexyl acrylate in Guaratinguetá is expected to start in 2015.

**Evonik builds specialty chemical facility for electronic chips**

August 18, 2011 — Evonik Industries AG has begun building a second hexachlorodisilane (HCDS) production facility in Rheinfelden, Germany. Production is scheduled to begin in the 2nd half of 2012. The company itself developed the hexachlorodisilane production process and successfully implemented it in Rheinfelden in September 2010 as the first plant put into operation. The second, new production facility is much larger and has a capacity of several tens of thousands of kilograms.

**KBR's to license its phenol technology to LG Chem**

August 17, 2011 — KBR was awarded a contract by LG Chem Ltd. (Seoul, South Korea; LG; www.lgchem.com) to license KBR's phenol technology for LG's 240,000-m.t./yr phenol plant in Daesan, South Korea. The new plant will be part of an integrated facility from cumene to bisphenol-A production. KBR will also provide the necessary engineering services in order to help LG meet its project schedule, which is targeting to be on-stream during the 1st half of 2013.

**UOP's Oleflex technology selected for propylene production in China**

August 2, 2011 — UOP LLC has been selected by Zhejiang Julong Petrochemical Co. (ZJLPC) to provide key technology for a new unit to produce propylene at its facility in Pinghu City, Zhejiang Province, China. The unit is expected to start up in 2013 and to produce 450,000 m.t./yr of propylene. The new propane dehydrogenation unit at the facility will use UOP's C3 Oleflex technology to convert propane to propylene.

**Fluor lands a major mining contract in Chile**

July 14, 2011 — Fluor Corp. (Irving, Tex.; www.fluor.com) has won a contract valued at approximately $1 billion from Minera Quadra Chile Limitada (Santiago), a subsidiary of Quadra FNX Mining Ltd. (Vancouver, B.C., Canada), to perform work at the company's Sierra Gorda project in Chile. Fluor will provide engineering, procurement and construction management (EPCM) services for the copper/molybdenum mine's processing plant. When complete, the mine will be capable of processing approximately 110,000 ton/d of ore, expanding to 190,000 ton/d during year four of operations. Quadra FNX is targeting first production from Sierra Gorda in 2014.

**Stamicarbon urea technology licensed to Hengang Huahe Coal Chemical Industry**

July 12, 2011 — Stamicarbon B.V. (Sittard, the Netherlands; www.stamicarbon.com), the licensing and IP Center of Maire Tecnimont S.p.A. (Rome, Italy; www.mairetecnimont.it), has signed a license agreement with Hengang Huahe Coal Chemical Industry, Ltd. in the Peoples' Republic of China (PRC) for a urea granulation plant with a capacity of 1,860 m.t./d. The plant will be built in Hegang City, Heilongjiang Province, PRC. The urea plant will use Stamicarbon Urea2000Plus Technology. Startup is planned in 2014.

## MERGERS AND ACQUISITIONS

**Dow to sell global polypropylene business to Braskem**

July 27, 2011 — The Dow Chemical Co. (Midland, Mich.; www.dow.com) has signed a definitive agreement under which Dow's global polypropylene business will be divested to Braskem (São Paulo, Brazil; www.braskem.com.br) for a total enterprise value to Dow of $340 million, comprised of $323 million cash purchase price, plus other cash and contingency assumptions of $17 million. The transaction is expected to close by the end of the 3rd Q of 2011, pending regulatory approval. The divestiture includes Dow's polypropylene manufacturing facilities at Schkopau and Wesseling, Germany, and Freeport and Seadrift, Tex. Dow's Polypropylene Licensing & Catalyst business and related catalyst facilities are excluded from the scope of the transaction. ■

*Dorothy Lozowski*

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

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FOR MORE ECONOMIC INDICATORS, SEE NEXT PAGE

# Economic Indicators

2009 2010 2011

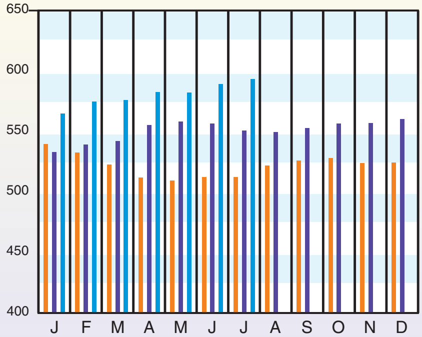
**DOWNLOAD THE *CEPCI* TWO WEEKS SOONER AT *WWW.CHE.COM/PCI***

## CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

| (1957-59 = 100) | July '11 Prelim. | June '11 Final | July '10 Final |
|---|---|---|---|
| ***CE* Index** | 593.2 | 588.9 | 550.7 |
| Equipment | 724.1 | 718.0 | 659.2 |
| Heat exchangers & tanks | 681.8 | 678.0 | 611.1 |
| Process machinery | 675.8 | 664.5 | 626.0 |
| Pipe, valves & fittings | 915.3 | 904.8 | 821.7 |
| Process instruments | 446.9 | 440.9 | 416.8 |
| Pumps & compressors | 909.5 | 904.7 | 902.4 |
| Electrical equipment | 512.5 | 510.8 | 481.6 |
| Structural supports & misc | 764.7 | 760.7 | 679.7 |
| Construction labor | 327.1 | 325.6 | 328.7 |
| Buildings | 520.6 | 519.1 | 506.7 |
| Engineering & supervision | 332.1 | 332.6 | 338.4 |

**Annual Index:**

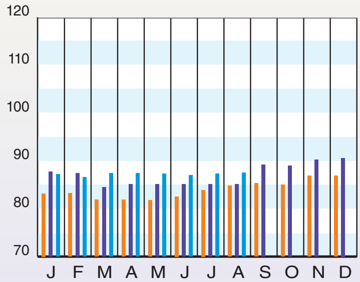
2003 = 402.0
2004 = 444.2
2005 = 468.2
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8



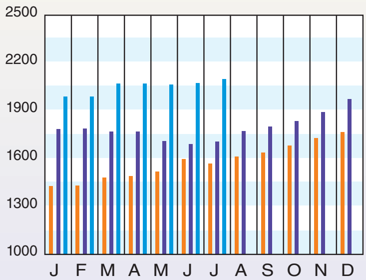

## CURRENT BUSINESS INDICATORS

| | LATEST | | PREVIOUS | | | | YEAR AGO | |
|---|---|---|---|---|---|---|---|---|
| CPI output index (2007 = 100) | Aug.'11 = | 87.5 | Jul.'11 = | 87.3 | Jun.'11 = | 87.0 | Aug.'10 = | 85.1 |
| CPI value of output, $ billions | Jul.'11 = | 2,100.2 | Jun.'11 = | 2,073.4 | May.'11 = | 2,065.1 | Jul.'10 = | 1,706.3 |
| CPI operating rate, % | Aug.'11 = | 75.5 | Jul.'11 = | 75.3 | Jun.'11 = | 75.0 | Aug.'10 = | 72.9 |
| Producer prices, industrial chemicals (1982 = 100) | Aug.'11 = | 336.5 | Jul.'11 = | 338.0 | Jun.'11 = | 342.6 | Aug.'10 = | 260.7 |
| Industrial Production in Manufacturing (2007=100) | Aug.'11 = | 90.7 | Jul.'11 = | 90.3 | Jun.'11 = | 89.8 | Aug.'10 = | 87.4 |
| Hourly earnings index, chemical & allied products (1992 = 100) | Aug.'11 = | 157.7 | Jul.'11 = | 159.2 | Jun.'11 = | 158.0 | Aug.'10 = | 158.3 |
| Productivity index, chemicals & allied products (1992 = 100) | Aug.'11 = | 110.2 | Jul.'11 = | 111.0 | Jun.'11 = | 111.0 | Aug.'10 = | 110.9 |

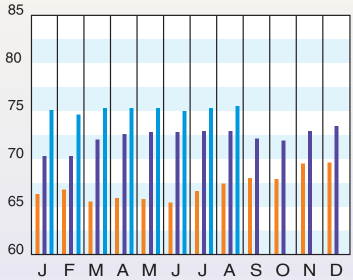
**CPI OUTPUT INDEX** (2007 = 100)




**CPI OUTPUT VALUE** ($ BILLIONS)




**CPI OPERATING RATE** (%)



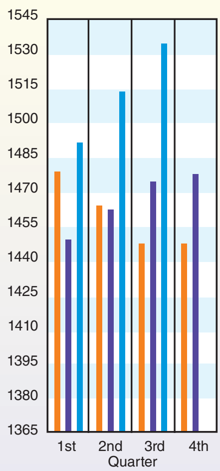

Current Business Indicators provided by Global Insight, Inc., Lexington, Mass.

## MARSHALL & SWIFT EQUIPMENT COST INDEX

| (1926 = 100) | 3rd Q 2011 | 2nd Q 2011 | 1st Q 2011 | 4th Q 2010 | 3rd Q 2010 |
|---|---|---|---|---|---|
| **M & S INDEX** | 1,533.3 | 1,512.5 | 1,490.2 | 1,476.7 | 1,473.3 |
| **Process industries, average** | 1,592.5 | 1,569.0 | 1,549.8 | 1,537.0 | 1,534.4 |
| **Cement** | 1,589.3 | 1,568.0 | 1,546.6 | 1,532.5 | 1,530.0 |
| **Chemicals** | 1,559.8 | 1,537.4 | 1,519.8 | 1,507.3 | 1,505.2 |
| **Clay products** | 1,579.2 | 1,557.5 | 1,534.9 | 1,521.4 | 1,518.3 |
| **Glass** | 1,491.1 | 1,469.2 | 1,447.2 | 1,432.7 | 1,428.5 |
| **Paint** | 1,608.7 | 1,584.1 | 1,560.7 | 1,545.8 | 1,542.1 |
| **Paper** | 1,502.4 | 1,480.7 | 1,459.4 | 1,447.6 | 1,444.5 |
| **Petroleum products** | 1,698.7 | 1,672.0 | 1,652.5 | 1,640.4 | 1,637.0 |
| **Rubber** | 1,641.4 | 1,617.4 | 1,596.2 | 1,581.5 | 1,579.3 |
| **Related industries** | | | | | |
| **Electrical power** | 1,517.6 | 1,494.9 | 1,461.2 | 1,434.9 | 1,419.2 |
| **Mining, milling** | 1,648.6 | 1,623.5 | 1,599.7 | 1,579.4 | 1,576.7 |
| **Refrigeration** | 1,884.4 | 1,856.4 | 1,827.8 | 1,809.3 | 1,804.8 |
| **Steam power** | 1,572.2 | 1,546.5 | 1,523.0 | 1,506.4 | 1,502.3 |

**Annual Index:**

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






## CURRENT TRENDS

Capital equipment prices, as reflected in the *CE* Plant Cost Index (CEPCI), increased approximately 0.73% on average from June to July, after increasing approximately 1.2% from May to June.

Meanwhile, according to the Current Business Indicators (see middle table) from Global Insight, Inc., August saw increases in the CPI output index, the CPI value of output and the CPI operating rate.

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