CHEMICAL ENGINEERING

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September 2015

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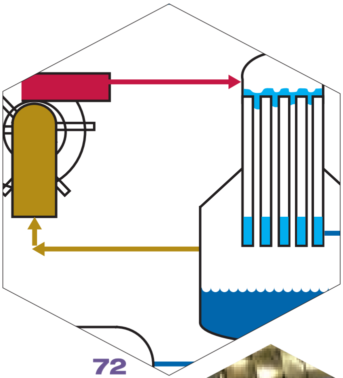

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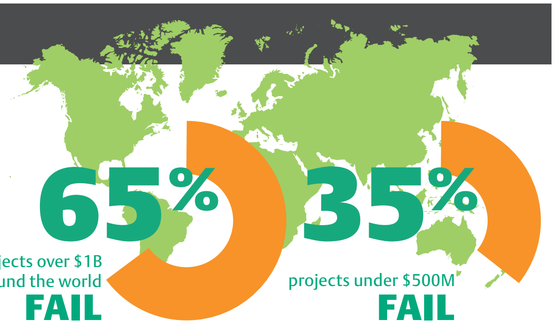
PROJECT SCHEDULE RISK

$135 million **AT RISK**

56% **INEFFECTIVE** communication

For every $1 billion spend on a capital project, $135 million is at risk. 56% of that ($75 million) is at risk due to ineffective communication.

–2013 Pulse of the Profession, Project Management Institute.



65% projects over $1B around the world **FAIL**

35% projects under $500M **FAIL**

A project is considered to have failed if the schedule slips or the project overspends by more than 25%, the execution time is 50% longer, or there are severe and continuing operational problems into the second year of the project.

–Speed Kills, Klaver, Ali. 2012 Project Manager Magazine.

40 percent of projects in the oil and gas industry are subject to budget and schedule overruns.

–Capital Project Execution in the Oil and Gas Industry. M. McKenna, H. Wilczynski, D. VanderSchee. 2006 Booz Allen Hamilton survey from 2006 of 20 companies (super-majors, independents and EPC firms).

budget & schedule **OVERRUNS** **40%**

30% anticipated value **DISAPPEARS**

Up to 30 percent of anticipated value disappears during the turnover/ commissioning and ramp-up phases of new asset lifecycles.

–Deloitte. Effective Operational Readiness of Large Mining Capital Projects - Avoiding value leakage in the transition from project execution into operations. Article, 2012.

20% cost savings

39% schedule **REDUCTION**

Good front end planning leads to as much as 20% cost savings and 39% schedule reduction for total project design and construction.

–Construction Industry Institute: Adding Value Through Front End Planning. CII Special Publication 268-3.

PERSONNEL

50% expected to **RETIRE**

50% of experienced and managerial personnel in national and international oil gas processing companies are expected to retire in the coming decade.

–Society of Petroleum Engineers, "The Great Crew Change: A Challenge for Oil Company Profitability", April 16, 2011.

6 TO 7 YEARS

It takes an average of six to seven years to develop new employees into autonomous petrotechnical professionals who can make non-standard, original technical decisions.

–2010 SBC Oil & Gas HR Benchmark, Schlumberger Business Consulting Energy Institute, March 2011.

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Editor's Page

Honoring 'green chemistry' achievements

The 2015 winners of the Presidential Green Chemistry Challenge Awards have been announced. Each year, the U.S. Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov) recognizes innovative technologies that reduce hazards to humans and the environment and the leading scientists who contribute to this end. These achievements are of great interest since developing safer and environmentally sustainable processes is an important goal for the chemical process industries (CPI). Details about the award and selection criteria can be found on the EPA's website.

The winners of the 2015 Presidential Green Chemistry Challenge Awards, in each of six categories, are described here (Source: EPA).

Designing Greener Chemicals Award — Hybrid Coating Technologies/Nanotech Industries (Daly City, Calif.; www.hybridcoatingtech.com) has developed a plant-based polyurethane for use on floors, furniture and in foam insulation. Conventional polyurethane production involves the use of isocyanates, a hazardous class of chemicals. Hybrid Coating Technologies produces its Green Polyurethane (also known as HNIPU or hybrid non-isocyanate polyurethane) without the use of isocyanates, and according to the company, its patented technology is the only formulation in the world to do so.

Greener Reaction Conditions Award — Soltex (Synthetic Oils and Lubricants of Texas; Houston; www.soltexinc.com) has developed a process based on a novel solid catalyst for polymerizing isobutylene monomer into polyisobutylene. The solid catalyst eliminates the need for a liquid catalyst that is hazardous to handle and that requires extensive water washing to remove. Soltex's process significantly lowers the water usage in the process, and reduces the use of a difficult-to-handle material.

Greener Synthetic Pathways Award — LanzaTech (Skokie, Ill.; www.lanzatech.com) was honored with this award for its gas fermentation process that uses waste gas that might otherwise be vented or flared, to produce useful products and reduce companies' carbon footprints. Gas streams containing a range of CO and H_2 levels can be used to produce ethanol and more. The company's proprietary microbes can also consume H_2-free gas streams.

Academic Award — Eugene Chen, professor at the Colorado State University (Fort Collins; www.colostate.edu) was recognized for his work in developing new condensation technology that uses plant-based materials to produce liquid fuels and renewable chemicals.

Small Business Award — Renmatix (King of Prussia, Penn.; www.renmatix.com) won this award for developing a process that uses supercritical water, instead of enzymes or acids, to break down biomass for use in bio-based processes.

Climate Change Award — Algenol (Fort Myers, Fla.; www.algenol.com) is the first recipient of this new award category. The company has received this honor for developing a patented technology using blue-green algae that use CO_2 to produce fuels such as ethanol.* ■

Dorothy Lozowski, Editor in Chief

* For more on these topics, see www.chemengonline.com, including Supercritical water process converts biomass to sugars, November, 2011; Microbes convert stack gases to fuels and chemicals, December, 2010; Reliance refinery launches demonstration module for Algenol biofuel-production process, January 21, 2015; and BASF and Renmatix agree on a joint development for the production of industrial sugars from biomass, December 18, 2013

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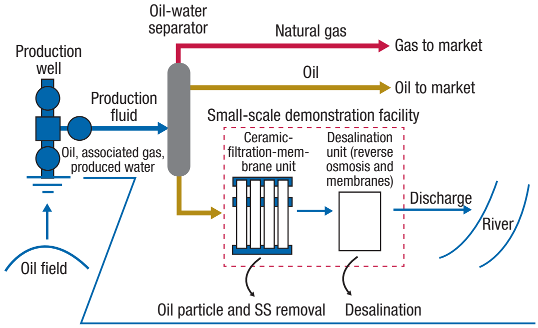
Ceramic membrane filtration to be demonstrated for removing oil from produced water

Edited by:
Gerald Ondrey

Japanese companies INPEX Corp. (Tokyo, www.inpex.co.jp), Chiyoda Corp. (Yokohama; www.chiyoda-corp.com), and Metawater Co., Ltd. (Tokyo, all Japan; www.metawater.co.jp) have been commissioned to build a small-scale demonstration facility that will use ceramic membrane filtration for treating produced water for Japan Oil, Gas and Metals National Corp. (JOGMEC). The commissioned work will take place at the Yabase Oil Field operated by INPEX in Akita Prefecture, and will run through January 31, 2016.



In bench-scale tests (3,600 L/d) performed in Japan during 2013 and 2014, the companies demonstrated a number of achievements: that ceramic membranes are not only capable of removing suspended solids (SS) but also oil particles; stable operation in the field condition for influent containing 10–400 mg/L of oil and 20–320 mg/L of SS; permeate water quality was stable and good enough at all times, with oil below 10 mg/L and SS below 5 mg/L; cross-flow filtration worked efficiently to reduce fouling and realized stable operation; and the combination of ceramic membranes and the reverse osmosis (RO) system produces water quality with total dissolved solids (TDS) below 500 mg/L.

Metawater's commercial ceramic-membrane element (180-mm dia. and 1,500-mm length) has a nominal pore size of 0.1 μm and a filtration area of 25 m^2, which corresponds to 75,000 L/d at a flux of 3 $m^3/m^2/d$. The ceramic membranes have been used commercially for over 17 years for the removal of suspended solids in municipal-water-purification facilities. The new pilot demonstration, which combines membrane filtration with RO (diagram) will demonstrate the membrane's ability for removing oil droplets, and will have a capacity to treat 150,000 L/d of produced water. This process is said to be simpler than existing technology, which requires multiple steps. The companies believe the successful demonstration of ceramic membrane-based produced water treatment will contribute to improved economics in oil field production, extend the life-spans of oil fields and reduce the environmental impact of oil production.

An attractive catalyst for making biodiesel fuels

It has been known for a long time that sulfonated active-carbon acid can catalyze both esterification and transesterification to produce biodiesel fuels from oils with high acid value without pretreatment. However, the separation of such catalysts requires filtration or centrifugation, which are energy intensive and time consuming. In order to enable the magnetic separation of this type of catalyst, professor Fang Zhen and his team at the Xishuangbanna Tropical Botanical Garden of the Chinese Academy of Sciences (Menglun, Yunnan Province; www.xtbg.cas.cn) have synthesized magnetic carbonaceous acid catalysts with high acidity and strong magnetism for biodiesel production from oils with high acid value. The catalyst allows production of biodiesel from crude Jatropha oil with high acid value (17.2 mg KOH/g) and high yields, a slight reduction in total acid density and high catalyst recovery rate of 96.3%. With the catalyst, the team has achieved a Jatropha diesel fuel yield of 90.5% at 200°C with three cycles.

To make the catalyst, the researchers used a five-step process involving double hydrothermal precipitation at 180°C and pyrolysis at 400 to 800°C, and subsequent sulfonation at 150°C. A pyrolysis temperature of 600°C was found to give a catalyst with high acid density (2.79 mmol/g) and strong magnetization (14.4 Am^2/kg). The magnetic catalyst directly esterifies and transesterifies high-acid-value oil without pretreatment, with high biodiesel yield and the catalyst was easily separated for three recycles with little deactivation. The team believes the catalyst could also find application in the pretreatment of oils with high acid value and in the hydrolysis of biomass.

Li-S BATTERY STORAGE

Anesco Ltd. (Reading, U.K.; www.anesco.co.uk) and OXIS Energy (Abingdon, U.K.; www.oxisenergy.com) have begun a collaboration to commercialize OXIS Lithium Sulfur Technology for battery storage for commercial and residential renewable installations. The new battery storage units will be available for installation from 2016.

OXIS' Li-S cells are composed of a metallic Li anode, a sulfur-based cathode (which includes carbon and a polymer binder) and a nonflammable electrolyte, which renders the cell inherently safe, says the company. In contrast with conventional Li-ion cells, the chemical processes include dissolution from the anode surface during discharge and reverse lithium plating to the anode while charging. As a consequence, Li-S allows for a theoretical specific energy in excess of 2,700 Wh/kg, which is nearly five times higher than that of Li-ion, says OXIS. The company has already demonstrated the technology in "pouch cells" with specific energy of 300 Wh/kg.

ETHANOL YIELDS

Yeast is a crucial element in the fermentation-based production of ethanol. Unfortunately, yeast can become damaged and ineffective as the concentration of ethanol rises, limiting ethanol production capabilities. A research team from the Massachusetts Institute of Technology (MIT; Cambridge, Mass.; web.mit.edu) found that injecting potassium phosphate into the reaction environment increased the yeast's ethanol tolerance, allowing for significantly higher ethanol yields.

(Continues on p. 8)

Note: For more information, circle the 56-digit number on p. 94, or use the website designation.

K$_3$PO$_4$, a readily available compound, serves as a natural pH buffer within the reaction mixture, lowering the acidity and enabling the yeast to tolerate larger amounts of ethanol. Also tested were Ca$_2$PO$_4$, Na$_3$PO$_4$ and (NH$_4$)$_3$PO$_4$, but none of these boosted ethanol production as effectively as K$_3$PO$_4$. The team has proven the effectiveness of potassium-dosed yeast by using raw-material samples from industrial fermentation processes. Larger-scale laboratory and pilot tests are planned, and the team sees that this acidity-controlling technology could be feasibly integrated into industrial-scale processes for the production of ethanol and other biofuels, such as butanol.

POWDERED MILK

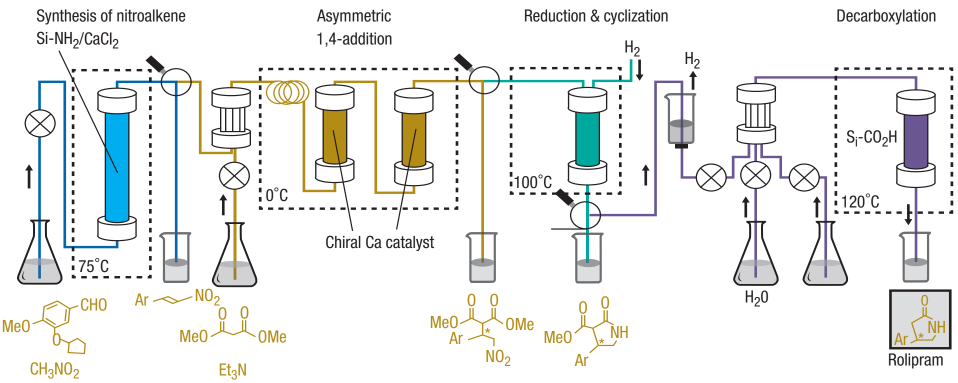
Finland's largest dairy company, Valio Oy (Helsinki; www.valio.fi), recently boosted the production of its Lapinlahti whey powder plant by over 10% by implementing the proprietary advanced process control (APC) system, Napcon, from Neste Jacobs Oy (Porvoo, Finland; www.nestejacobs.com). Valio is also optimizing a milk powder plant in Seinäjoki, Finland, in which Napcon is controlling both an evaporator and a spray dryer.

Whey and milk powders are produced by spray drying, which is very energy intensive. The moisture content of the final product is critical. If it is too moist, the powders are sticky; if it is too dry, excess energy is used and dust is generated. Napcon balances the need of energy within the desired product specifications so that the energy consumption is minimized. Napcon can also predict the moisture content and adjust the water balance in realtime, while adapting to changes in outdoor humidity.

The Napcon solution in Valio's two production plants consists of two tools: Napcon Indicator, which calculates the material and energy

(Continues on p. 10)

Continuous multi-step synthesis of fine chemicals



Currently, the active components of most pharmaceuticals and fine chemicals are synthesized by multiple batch reactions, in which all starting materials are mixed in reaction vessels and the desired compounds are extracted and purified after each reaction has finished. Such methods require excess energy and many operational steps, and often generate a significant amount of waste. Although continuous flow reactors have advantages over batch reactors, it has been difficult to adopt the technology for complex, multi-step reactions.

Now, professor Shu Kobayashi and his research group at the University of Tokyo (Tokyo, www.u-tokyo.ac.jp) have developed highly active, immobilized heterogeneous catalysts for column reactors, which enables the multi-step synthesis of pharmaceuticals. The researchers have demonstrated the continuous flow reactors for the eight-step production process (diagram) of (R)-rolipram, an anti-inflammatory drug. The complete synthesis did not require the isolation or purification of intermediates or the purification of products from catalysts. By simply replacing a column packed with a chiral heterogeneous catalyst with another column packed with the opposing enantiomer, the researchers were able to produce (S)-rolipram.

"This new technology can be applied to not only other γ-aminobutyric acids and medicines but also various chemicals such as flavors, agricultural chemicals, and functional materials," says Kobayashi.

Phosphorus-free cooling water treatment

A new technology for treating cooling tower water is designed to control scale formation and provide corrosion protection without using phosphorus-containing compounds. Phosphorus from wastewater discharge is known to be a major factor in fueling algae blooms and excessive aquatic plant growth, which can have a severe negative impact on the ecosystems of lakes, rivers and bays. As a result, regulations governing allowed levels of phosphorus in cooling-tower-water discharge have become increasingly stringent, reaching 0.075 to 0.04 parts-per-million (ppm) in sensitive areas.

U.S. Water Services, Inc. (U.S. Water; St. Michael, Minn.; www.uswaterservices.com) has launched a product, known as PhosZero, that uses a proprietary blend of organic carboxylic acid materials and organic polymers and copolymers to control scale and prevent corrosion without the need for phosphorus-containing chemicals. The anti-scale components work by threshold inhibition, crystal lattice modification and dispersion, and the corrosion production is achieved through the formation of a protective iron-oxide layer, explains LaMarr Barnes, U.S. Water's vice president of Marketing and Business Development. The blend of ingredients in PhosZero gives rise to synergistic effects that enhance the performance of the product, he adds.

While helping companies to comply with limits on phosphorus discharge, PhosZero also helps plants reduce costs, by avoiding the need to remove phosphorus from waste streams, and improve safety, by reducing the need for on-site acid storage, the company says.

The product is currently in use at a handful of plant sites in the U.S., Barnes says, and the results of corrosion monitoring have been favorable. U.S. Water is working on developing a complete understanding of the corrosion inhibition mechanisms of PhosZero and testing its corrosion-protection performance on different metallurgies.

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balance information; and Napcon Controller, which controls the process using multivariable model-predictive control (MMPC). An OPC UA connection (Open Process Control Unified Architecture) is implemented between Napcon and Valio's process control systems.

NANOPAPER DEVICE

Researchers led by Jun Zhou of Huazhong University of Science & Technology (Wuhan, China; www.hust.edu.cn), and by Liangbing Hu of the University of Maryland (College Park; www.umd.edu), have designed a transparent paper-based, self-powered and human-interactive flexible system. The system is based on an electrostatic-induction mechanism requiring no extra power. It works like a nanopaper-based generator that converts mechanical

(Continues on p. 11)

A sound way to degas aluminum melts

During casting of aluminum alloys, degassing is required to remove hydrogen from the molten metal in order to prevent porosity in the solid metal that deteriorates its properties and performance. Currently, the so-called argon rotary degassing is used, where a porous graphite rotor is submerged into the melt and Ar is purged through the rotor to the bottom of the bulk melt. Although well established, Ar rotary degassing has some drawbacks, such as high dross formation and potential damage of the graphite rotor with subsequent melt contamination; it is also energy intensive and consumes expensive Ar, explains professor Dmitry Eskin of the Brunel Center for Advanced Solidification Technology, Brunel University London (U.K.; www.brunel.ac.uk/bcast).

Having proved that ultrasound degassing of molten aluminum alloys is cleaner, "greener" and just as efficient as current methods, a team of scientists from Brunel University, working within a European consortium, is developing a continuous process that will allow the degassing of much larger melt volumes and upstream from the casting mold, says Eskin. The Brunel researchers have developed a plate sonotrode — a part that transmits ultrasound to the melt — that has been shown to be more efficient than standard cylindrical sonotrodes. In laboratory trials (treating 10–25 kg of Al; flowrate of 3–4 kg/min), "our experiments showed that a plate sonotrode gave a continuous degassing efficiency of at least 50% in the melt flow rising to 75% in batch operation," says Eskin.

Eskin believes that much greater efficiencies are simply waiting to be unlocked and is seeking an industrial partner to help his team address some of the engineering challenges. "For example, we found that the connecting the flat sonotrode to the ultrasonic transducer and the shape and dimensions of the plate sonotrode should be optimized through engineering solutions to assure industrial-scale operation." Meanwhile, prototypes with "conventional" cylindrical sonotrodes for batch ultrasonic degassing are now being tested in participating foundries in Hungary and Austria. If successful, Spanish partner Hormesa (www.hormesa-group.com) will be able to supply commercial machines, says Eskin.

A step forward for the production of bio-based glucaric and adipic acids

Last month, Johnson Matthey Process Technologies (JMPT; London, U.K.; www.matthey.com) and Rennovia Inc. (Santa Clara, Calif.; www.rennovia.com) successfully started-up a fully integrated mini-plant for production of glucaric acid from glucose using jointly developed technology. The mini-plant is located at the JMPT R&D Center in Stockton, England.

The first phase of the project has started-up, whereby glucose is catalytically oxidized to glucaric acid. This takes place in a standard fixed-bed reactor using a proprietary supported-metal heterogeneous catalyst operating with air, water and glucose. This process is said to be simpler and cleaner than conventional routes that use nitric acid oxidation, which produces oxides of nitrogen (NOx) as a byproduct. The new route also has a higher yield and selectivity, says JMPT.

Also underway is the design and construction of the second phase of the facility, which is scheduled for completion in mid 2016. In this phase, jointly developed technology for the catalytic hydrogenation of glucaric acid to adipic acid will be further developed. "The learnings from this mini-plant will provide the design basis for commercial-scale manufacturing facilities, and will enable us to provide licensees with process guarantees," says David Prest, managing director JMPT's Chemicals Business.

The two companies began their collaboration in March 2014 to develop and commercialize production technology for bio-based glucaric acid and adipic acid. Adipic acid, an industrial chemical conventionally derived from petroleum, is a multi-billion dollar global market, with major applications in nylon fibers and engineering polymers, polyester polyols for polyurethanes, and adipate esters for phthalate-free plasticizers. Glucaric acid, an intermediate in the production of adipic acid, is an emerging platform chemical with a wide range of applications in detergents and cleaners, concrete formulations, de-icing and anti-corrosion markets.

energy into electric power.

To make the device, two sheets of nanopaper are coated with carbon nanotubes to serve as the electrodes. One of the electrodes is coated with a 30 μm-thick polyethylene (PE) film, which is then subjected to an electric field, making it negatively charged. This induces balanced positive charges on the nanotube film surfaces next to the PE. The edges of the two sheets are then pressed together, with the PE in the middle and leaving a tiny air gap between the sheets. Pressing the device narrows the air gap, bringing the PE-coated electrode closer to the other electrode, increasing the positive charge on that electrode. This creates a low current through the device; releasing the pressure causes the electrons to flow back. Therefore, repeated pressing and releasing creates a continuous current.

TRANSPARENT SOLAR FILM

Earlier this year, Ubiquitous Energy, Inc. (Redwood City, Calif.; www.ubiquitous.energy.com) debuted its ClearView Power technology at Dis-

(Continues on p. 13)

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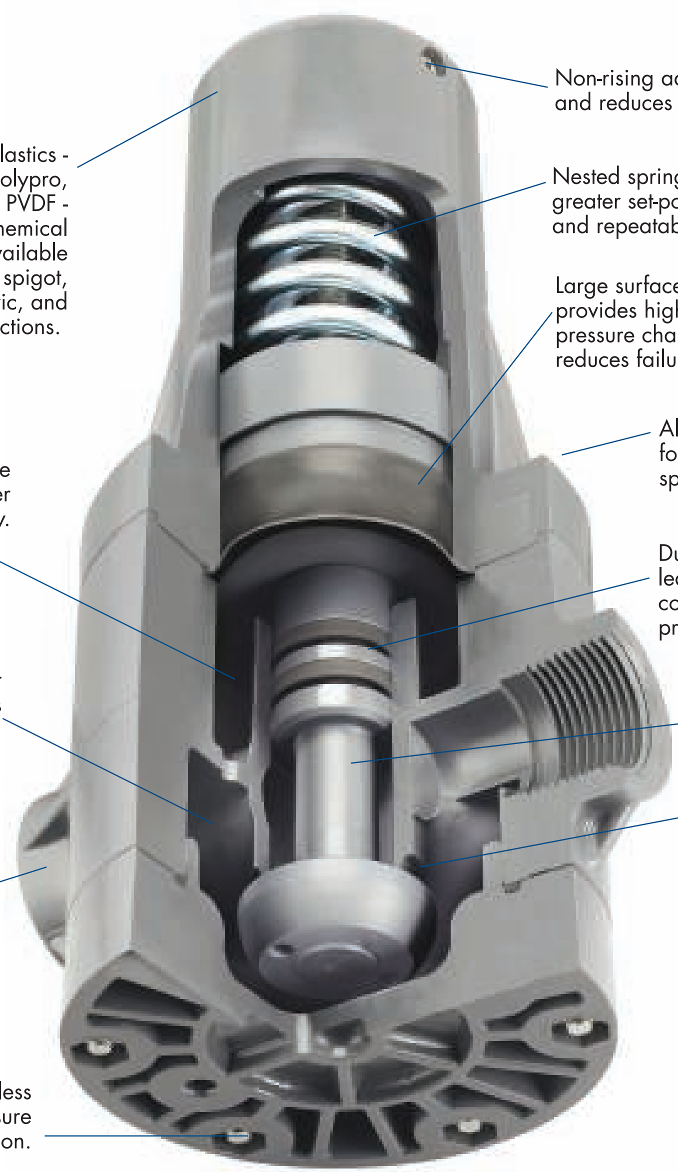

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This wastewater-treatment process also captures carbon dioxide

Researchers from the University of Colorado Boulder (Boulder, Colo.; www.colorado.edu) have developed a technology that combines wastewater treatment and carbon capture, resulting in a carbon-negative process that actually produces energy. The technology — called microbial electrolytic carbon capture (MECC) — takes advantage of the pH of the water-treatment environment to capture the carbon dioxide that is generated not only during degradation of the organic components in the wastewater, but also the CO_2 from fluegas or the atmosphere.

In laboratory demonstrations, a sample of wastewater from a shale gas well was fed into the anodic side of a two-chambered reactor in the presence of microbial bacteria and calcium silicate ($CaSiO_3$). The wastewater serves as an electrolyte, providing protons and dissolving the calcium silicate, as the bacteria breaks down the organic compounds within the water. Using an abundant mineral like calcium silicate is akin to the way nature captures CO_2, says Zhiyong Jason Ren, the study's lead researcher. He also noted that flyash, a residual waste stream from power plants, can also be used for this purpose. As the metallic calcium ions move across the reactor's cation-exchange membrane (CEM), CO_2 is captured and converted, forming a calcium carbonate ($CaCO_3$) deposit on the surface of the reactor. In laboratory tests, the MECC process was able to capture CO_2 with an efficiency of up to 93%. Additionally, the reaction creates clean fuel in the form of hydrogen gas, which can be used within a fuel cell for electricity production.

According to Ren, the largest challenge in commercializing this technology will be the integration of an efficient method for recovering the $CaCO_3$ product so that it can be sold or re-purposed. Currently, the team is gauging interest in the process with a Denver-based energy and utilities companies, and a pilot demonstration is planned once funding is received.

play Week 2015, the Society for Information Display's international symposium and exhibition (June 2–3; San Jose, Calif.). Implemented as a fully transparent film that covers a device's display area, ClearView Power technology transmits 90% of visible light, while selectively capturing and converting ultraviolet and near-infrared light into electricity — with efficiencies of more than 10% — to power the device and extend its battery life. The company was spun out of the Massachusetts Institute of Technology (MIT; Cambridge; www.mit.edu), and is now developing its highly transparent, efficient solar cells at its pilot production facility.

HYBRID PHOTOCATALYST

Although titanium dioxide is a well-known photocatalyst, it has a large band gap (3.2 eV), which means higher-energy ultraviolet radiation (wavelength less than 390 nm) is needed for photoactivation. TiO_2 also has a very low lifetime for the charge carriers and leads to a faster recombination rate. To overcome these difficulties, chemists

(Continues on p. 14)

from the University of Malaya (Kuala Lumpur, Malaysia; www.um.edu.my) and the Leibniz University of Hannover (Germany; www.uni-hannover.de) have developed a new hybrid photocatalyst — a well-organized, reduced graphene oxide (RGO) and silver-wrapped TiO_2 nanoparticle, which is described in a recent issue of *APL Materials,* a publication of the American Institute of Physics (AIP).

Adding Ag to the surface of the TiO_2 nanoparticles enhances the charge separation, and also shifts the wavelength at which the photocatalyst is activated by inducing localized surface plasmon resonance effects. The Ag/TiO_2 nanoparticles are then wrapped in sheets of RGO, which further reduces the nanoparticles band gap.

In laboratory studies, the hybrid photocatalyst was shown to degrade bisphenol A (BPA) — a well-known micropollutant classified as an EDC (endocrine-disrupting compound) —under visible light irradiation, with a removal efficiency of more than 60%. The researchers believe the catalyst shows promise for removing BPA and other micropollutants from water supplies.

Selective removal of micropollutants

Micropollutants, such as antibiotics and flame retardants, can pose a health threat to animals and humans, even in tiny concentrations. Current methods to remove micropollutants from the environment include adsorption onto powdered activated carbon, which is then separated from the wastewater and burned. This process can be costly because the organic matter present in the wastewater is also adsorbed onto the powder, and a lot of the activated carbon is consumed in the treatment process.

Another method, ozone treatment, breaks down the micropollutants through oxidation, but this can produce harmful byproducts such as formaldehyde. To avoid those pitfalls, scientists from Dalian University of Technology (Dalian, China; www.dlut.edu.cn) developed a two-step method to target those micropollutants. In the first step, insoluble polymers made of cyclodextrins cross-linked with epichlorohydrin are used as adsorbents. Cyclodextrins, derived from starch, selectively trap small hydrophobic organic compounds. The doughnut-shaped cyclodextrins have a hydrophobic cavity than can encapsulate micropollutants while excluding the larger organic matter that can clog the activated carbon. In the second step, potassium permanganate is used to degrade the captured compounds into less harmful substances, such as carbon dioxide, water and organic acids. The scientists tested their method in samples of distilled water and lake water containing the flame retardant tetrabromobisphenol A (TBBPA) and one of 13 antibiotics, each at concentrations of 50 ng/L and 50 µg/L. It was found that cyclodextrin adsorbed 94% of TBBPA and 12 to 79% of the antibiotics within 4 h. Treatment of the pollutant-loaded cyclodextrin with 100 µmol/L $KMnO_4$ degraded more than 91% of the adsorbed pollutants within 2 h.

The scientists believe their method could target any organic micropollutant that can be degraded by $KMnO_4$ oxidation, including many pesticides, pharmaceuticals, personal care products and organic solvents. ■


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Plant Watch

Chambroad commissions China's first C_3/C_4 coproduction plant

August 12, 2015 — UOP LLC (Des Plaines, Ill.; www.uop.com) announced that Shandong Chambroad Holding Co. has become the first company in China to commission a combined propylene and isobutylene (C_3/C_4) dehydrogenation unit based on UOP process technology. The unit, which is said to be the second of its kind, will produce 116,000 metric tons per year (m.t./yr) of propylene and 104,000 m.t./yr of isobutylene.

ExxonMobil selects Jacobs for EPCM work on Beaumont refinery expansion

August 11, 2015 — ExxonMobil Corp. (Irving, Tex.; www.exxonmobil.com) has selected Jacobs Engineering Group Inc. (Pasadena, Calif.; www.jacobs.com) to perform engineering, procurement and construction management (EPCM) services for the expansion of Exxon's refinery in Beaumont, Tex. The project will add flexibility to process light crudes, increasing production capacity by approximately 20,000 barrels per day (bbl/d).

BASF to increase production capacity for chelating agents in Ludwigshafen

August 11, 2015 — BASF SE (Ludwigshafen, Germany; www.basf.com) is investing in the expansion of its production facilities to manufacture chelating agents, including biodegradable methylglycinediacetic acid, at its site in Ludwigshafen. The project is scheduled for completion in late 2016.

BioAmber opens world's largest succinic acid production facility

August 6, 2015 — BioAmber Inc. (Montreal, Canada; www.bio-amber.com) and Mitsui & Co. have opened the BioAmber Sarnia plant, which produces 30,000 m.t./yr of bio-based succinic acid from glucose. With over $140 million invested in its construction, the BioAmber Sarnia plant is said to be the world's largest succinic acid production facility.

H.B. Fuller breaks ground on new adhesives plant in Indonesia

July 30, 2015 — H.B. Fuller Co. (St. Paul, Minn.; www.hbfuller.com) broke ground on a new adhesives manufacturing facility in Surabaya, Indonesia. The company anticipates production of hot-melt and water-based adhesives products to begin in the second quarter of 2016.

Messer to build new oxygen production plant in Estonia

July 30, 2015 — As part of the joint venture (JV) Elme Messer Gaas, Messer Group GmbH (Bad Soden, Germany; www.messergroup.com) and the BLRT Grupp have invested around €5 million in a new oxygen-production plant in Järvakandi, Estonia. The plant produces 2,650 m^3/h of oxygen, supplying a local manufacturer of container glass.

Yara invests in urea granulation capacity expansion

July 30, 2015 — Yara International ASA (Oslo, Norway; www.yara.com) is investing $263 million to increase granulation capacity in Sluiskil, the Netherlands, enabling increased production of granular urea. A newly installed granulator will have a capacity of 660,000 m.t./yr of urea. Completion of the expansion is expected in the second half 2017.

MHI and Mitsubishi to build large-scale fertilizer plant in Uzbekistan

July 23, 2015 — Mitsubishi Heavy Industries, Ltd. (MHI; www.mhi-global.com) and Mitsubishi Corp. (MC; both Tokyo, Japan; www.mitsubishicorp.com) will build a large-scale production plant for ammonia and urea fertilizer for Navoiyazat Joint Stock Co. in Navoiy, Uzbekistan. The plant will have the capacity to produce 2,000 m.t./d of ammonia and 1,750 m.t./d of urea granules.

GFBiochemicals starts up commercial-scale plant for bio-based levulinic acid

July 20, 2015 — GFBiochemicals Ltd. (Milan, Italy; www.gfbiochemicals.com) has started commercial production at its new plant in Caserta, Italy, which has a production capacity of 10,000 m.t./yr of bio-based levulinic acid. The plant produces levulinic acid directly from biomass, and is said to be the world's largest commercial-scale production plant for levulinic acid.

Mergers & Acquisitions

Repsol and Grupo KUO receive approval for Dynasol JV merger

August 10, 2015 — Grupo KUO, S.A.B. de C.V. (Bosques de las Lomas, Mexico; www.kuo.com.mx) has obtained approval for contribution to Dynasol, a 50/50 JV with Repsol S.A. (Madrid, Spain; www.repsol.com). The JV consists of Grupo KUO's Mexico- and China-based emulsion rubber and nitrile businesses and Repsol's Spain-based chemical accelerators business.

Lonza acquires New Zealand-based crop-chemistry company Zelam

August 10, 2015 — Lonza (Basel, Switzerland; www.lonza.com) has acquired Zelam, a research-focused chemical company based in New Zealand that develops and manufactures products for crop protection, specializing in fungicides, insecticides, herbicides, foliar nutrients and additives. Zelam has facilities in New Zealand, as well as in Australia and the U.S.

LyondellBasell to acquire polypropylene compounds manufacturer in India

August 10, 2015 — LyondellBasell (Rotterdam, the Netherlands; www.lyondellbasell.com) has entered into a definitive agreement for the acquisition of SJS Plastiblends Pvt., a polypropylene compounds manufacturer located in Aurangabad, Maharashtra, India. The transaction is expected to close in late 2015.

Fluor divests Spanish operations to Sacyr Industrial, forming new JV

July 30, 2015 — Fluor Corp. (Irving, Tex.; www.fluor.com) has signed an agreement to divest 50% of shares in its Spanish operations, Fluor S.A., to Sacyr Industrial S.L.U. (Madrid, Spain; www.sacyr.com), a multinational construction company. The new JV entity, SacyrFluor, will be headquartered in Fluor's Madrid operations center. The value of the divestiture is €39 million.

Solvay strengthens aerospace presence with Cytec acquisition

July 30, 2015 — Solvay S.A. (Brussels, Belgium; www.solvay.com) will acquire Cytec (West Paterson, N.J.; www.cytec.com) for a total cash consideration amounting to $5.5 billion. Cytec's composites businesses will be integrated into Solvay's Advanced Materials operating segment. Cytec's mining chemicals and niche additives and phosphine specialty-chemical businesses will become part of Solvay's Advanced Formulations segment.

Honeywell acquires Elster from Melrose Industries for $5.1 billion

July 29, 2015 — Honeywell (Morristown, N.J.; www.honeywell.com) signed an agreement to acquire the Elster Division of Melrose Industries plc, a provider of thermal gas solutions, for approximately $5.1 billion. Elster also manufactures flow computers and regulators. The acquisition is anticipated to occur in the first quarter of 2016.

BASF to consolidate all pigments activities in new business unit

July 22, 2015 — BASF will form a global business unit combining all of its pigments activities effective January 2016. In the second half of 2016, BASF intends to carve out its pigments business and establish separate legal entities. The new business unit will likely be headquartered in the Ludwigshafen, Germany area.

Watson-Marlow acquires MasoSine pumps business in Japan

July 21, 2015 — Watson-Marlow Fluid Technology Group (WMFTG; Cornwall, U.K.; www.wmftg.com) has acquired the MasoSine sinusoidal pump manufacturing and distribution business from Primix Corp., through its parent company Spirax-Sarco Engineering plc, for £2.8 million. Co-branded as Watson-Marlow Primix, the new company will be headquartered in Tokyo. ■

Mary Page Bailey

Concrete: Modern Engineering for an Ancient Material

Novel additives, improved understanding of cement chemistry and thoughtful mix design are making modern concrete increasingly sustainable, durable and versatile

IN BRIEF

- DRIVERS OF CONCRETE INNOVATION
- RECYCLED MATERIALS
- CO_2 INCORPORATION
- ULTRAHIGH PERFORMANCE
- CRACK RESISTANCE
- CONCRETE APPLICATION
- MOLECULAR ANALYSIS

Concrete's origins can be traced back to the ancient world. For example, many believe that missionaries in North America learned to make natural cement from native peoples in Mexico, and a form of cement-based concrete was used to build iconic structures like the Colosseum and Pantheon in Ancient Rome. Despite its long history, concrete continues to experience significant levels of technical innovation, driven by increasing demand for more durable, more sustainable and higher-performing materials.

Modern concrete manufacturers and users seek greater durability for longer-lasting structures, higher environmental sustainability from manufacture to use, and products with properties more closely tailored to specific applications. To achieve gains in these areas, the concrete industry has focused on three broad areas: leveraging the chemistry of cement to achieve desired performance and environmental properties; devising new concrete mix designs that improve durability, functionality, aesthetics and other properties; and developing new additives to modify concrete behavior both before and after setting.

Drivers of concrete innovation

Concrete has general properties — including strength, durability, versatility, relative low cost and abundant raw materials — that make it the most used building material in the world by far. The terms concrete and cement are often incorrectly used interchangeably. Cement refers to an ingredient of concrete that undergoes chemical reactions to set and harden. Concrete is a mixture of cement, sand, gravel, water and additives that is used for building (see sidebar, p 24).

Demand for concrete is driven by a combination of macro-scale trends, such as global urbanization, and the increasing need for sustainability of buildings and infrastructure.

Steve Amey, manager of strategic development, and Tate Coverdale, director of development, both for BASF's North American Construction Chemicals division (www.master-builders-solutions.basf.us) say that rising energy demand and the need for efficient use of natural resources is forcing the construction industry to focus on solutions that lower utility demand and reduce noise and waste, while building more durable, longer-lasting structures. These goals can often be achieved with less CO_2 emissions and less heat retention. Meanwhile, there is also movement toward easier-to-maintain buildings, and safer structures that require less labor to build, Amey and Coverdale state.

Builders are looking for concretes with properties that lower its overall carbon footprint, while also easing costs and facilitating its use. "End-users are looking for reliable performance from concrete despite the inevitable variability of the raw materials," explainsDave Myers, vice president of technology and marketing for Grace Construction Products (part of W.R. Grace & Co.; Cambridge, Mass.; www.grace.com/construction). While builders are focused on cost, performance and application, concrete producers have been challenged by the lower availability of high-quality aggregates. "Concrete producers are trying to figure out ways to make high-quality concrete with low-quality aggregate," Myers says. In general, he notes, they are succeeding through more sophisticated mix designs and the use of chemical admixtures that correct for the impact that aggregates can have on concrete rheology.

The concrete industry has moved significantly in the direction of specialization, developing a broader portfolio of concrete mixtures and products that are more tailored for specific end uses. "There's been a tremendous amount of innovation and creativity in the concrete industry over the past 20 years," says Julie Buffenbarger, a construction specialist at LafargeHolcim (Chicago, Ill.; www.lafarge-na.com). Buffenbarger also chairs the Concrete Joint Sustainability Initiative (www.

FIGURE 1. Cement is a component of concrete that binds together gravel and sand

sustainableconcrete.org) and the American Concrete Institute's (ACI; Farmington Hills, Mich.; www.concrete.org) sustainability committee. "Concrete is not 'plain Jane' anymore — by applying the tools of modern science and engineering, the concrete industry has drastically expanded concrete's performance, aesthetic appeal and its impact on the environment," she explains.

Improving durability, increasing specialization and softening environmental impact all require better-understood, more highly engineered concrete products. Effective concrete admixtures and thoughtful concrete mix designs are critical in obtaining desired properties, Grace's Myers says. The industry is responding within a number of areas, from new cement chemistries and more complex concrete mix designs, to less labor-intensive methods of concrete application that utilize self-consolidating concrete.

Recycled materials

The concrete industry is heavily focused on reducing its environmental footprint by promoting sustainability intitiatives that include minimizing energy use, reducing emissions, conserving water, minimizing waste and increasing recycled content.

The increased use of alternative raw materials, such as recycled aggregates for concrete, and supplementary cementitious materials for cement — the material that binds concrete together — has become a key strategy, explains Lafarge's Buffenbarger. For example, old concrete from demolished buildings or pavement is being crushed and recycled as aggregate material for new concrete to save natural resources. Researchers are also investigating other recycled materials, including ground glass from recycled bottles, crumb rubber from tires, plastics, fibers, recycled asphalt pavement and mineral and inert fillers as alternative raw materials for concrete, Buffenbarger says.

Using concretes with higher levels of recycled materials helps contribute toward credits in the LEED (Leadership in Energy and Environmental Design) rating system, Grace's Myers notes.

While comprising only 7–15% of concrete's volume (Figure 1), cement is responsible for high greenhouse-gas emissions due to an energy-intensive process and liberation of CO_2 during production. Along with improvements in cement manufacturing equipment and increased use of alternative fuels, the use of alternative raw materials in cement production, and substituting alternative materials into clinker (the product of the cement-making process), are helping to lower the CO_2 and energy impact of cement.

Blended cements are those that combine traditional portland cement with supplementary cementitious materials, including fly ash, slag cement (ground blast-furnace slag) or silica fume — all waste products from other industries. By using higher levels of waste materials and therefore lower amounts of portland cement, CO_2 emissions can be lowered.

Efforts are also aimed at developing admixtures that can help enable higher proportions of blended cement to be used, so the level of portland cement can again be reduced.

Although there has been considerable work on optimizing the use of flyash, slag and silica fume in cement, these are considered "traditional" supplementary cementitious materials. More recently, researchers and concrete industry players have expanded their search for alternative recycled materials to see what roles they could play in new concrete formulations, Buffenbarger says. These include calcined shale, ash from municipal solid waste, rice husk ash and a host of others, she says.

CO_2 incorporation

Other efforts to lower the CO_2 footprint of the industry target utilization of CO_2 gas in positive ways.

CarbonCure Technologies (Halifax, Nova Scotia; www.carboncure.com) has developed a technology for incorporating waste CO_2 into mixed concrete. The company's system injects post-industrial CO_2 into mixed concrete in a way that is analogous to the addition and use of conventional concrete admixtures, explains Christie Gamble, director of sustainability for CarbonCure. When CO_2 comes into contact with water in freshly mixed concrete, it forms carbonate ions, which react with calcium ions from the cement to form solid $CaCO_3$. The formation of calcium carbonate can contribute to increased concrete strength while mineralizing the carbon. The CarbonCure gas-injection system, which is a sample retrofit added into existing concrete manufacturing facilities, contains analytical equipment that optimizes the CO_2 conversion and concrete performance, Gamble says.

By achieving the beneficial re-use of CO_2 with CarbonCure's system, concrete producers can realize environmental benefits and help architects of buildings that are seeking LEED certification. In ready-mixed applications, the company anticipates further benefits on the operational side, where efficiencies realized by the strength benefits of the CO_2-containing concrete may enable the producer to reduce the cement content. With a system already on the market for masonry block manufacturers, CarbonCure is planning to launch a system for ready-mix concrete applications this Fall.

Meanwhile, Solidia Technologies (Piscataway, N.J.; www.solidiatech.com) developed a new type of calcium-silicate-based cement that consumes CO_2 as part of the curing process. Its cement differs from regular portland cement in how it sets and hardens. Solidia cement can reduce CO_2 emissions in final concrete products by up to 70%, Solidia says.

As opposed to forming di- and tricalcium silicate hydrates, as in portland cement, Solidia cement relies on a patented process called reactive hydrothermal liquid-phase densification (rHLPD) that promotes binding between monocalcium silicate ($CaSiO_3$) and CO_2 to cure the material, rather than relying on hydrate formation (see *Chem. Eng.* Sept. 2013, p. 11). To harden Solidia concrete, CO_2 is introduced to a water-containing concrete slurry, where the gas dissolves and begins leaching calcium from the $CaSiO_3$. This process forms $CaCO_3$, which precipitates out of solution to lock particles in place, effectively sequestering CO_2 in the concrete.

According to Solidia, recent testing of its concrete by engineers at Purdue University (West Lafayette, Ind.; www.purdue.edu) and Solidia indicate that the CO_2-cured concrete performs comparably to or better than traditional concrete made with Portland cement in resistance to cold weather and extreme conditions.

Another low-CO_2 cement effort is Project Aether, a public-private consortium aimed at developing and producing low-carbon cements that generate less CO_2 in the production process. Run by Lafarge, the consortium is now testing the production process for Aether cement, a variety that requires less limestone than portland cement and that is made with less energy.

According to Lafarge's Buffenbarger, the CO_2 footprint of traditional portland cement is 816 kg CO_2 per ton of cement, while the Aether and Solidia cements total 571 and 570 kg CO_2 per ton, respectively.

Ultra high performance

In the past decade, the use of a new class of concrete known as ultra high-performance concrete (UHPC) has expanded, increasing the versatility of the material by introducing higher strength and ductility, and by providing opportunities for innovation to concrete makers and builders. According to the Portland Cement Association (PCA; Skokie, Ill.; www.cement.org), "the ductile behavior of [UHPC] is a first for concrete, with the capacity to deform and support flexural and tensile loads, even after initial cracking." UHPC combines portland cement, silica fume, quartz flour and fine sand with superplasticizer additives and organic or steel fibers.

Circle 8 on p. 94 or go to adlinks.chemengonline.com/56201-80

Because of its unique properties, UHPC can accomplish what traditional concrete can with substantially reduced levels of material, which can lead to cost savings and environmental benefits. The Lafarge product Ductal is an example of a UHPC that has been used in a variety of building and infrastructure applications.

Crack resistance

Concrete cracking can lead to the corrosion of steel reinforcement structures and jeopardize mechanical properties. A number of modern approaches in concrete technology are aimed at the issue of cracking.

Entrainment of air into concrete makes the material more resistant to freeze-thaw cycles that can introduce and propagate cracks. The inclusion of microscopic air pockets acts to relieve internal stress on the concrete by providing places for water to expand into when it freezes. Although effective, air-entrainment of concrete is challenging in practice. Surfactants have long been used to entrain air bubbles in concrete, and the practice works well generally, but has considerable variability, says BASF's Coverdale. To improve performance in this area, and eliminate the need for air-entrained concrete, BASF is developing a microsphere-based admixture technology.

The admixture product eliminates the variability observed with the use of surfactants for air-entrainment. The microspheres are hollow particles that are more like balloons than bubbles, says Coverdale. With diameters of less than 100 microns, the microspheres have a polymeric shell that is highly resilient, tough and flexible. Similar to entrained air voids, these microspheres provide stress relief zones during the expansion of freezing water within concrete, BASF says.

The company says this technology will help eliminate the challenges associated with manufacturing and placing traditional air-entrained concrete, including controlling the entrained air in concrete that has variable ingredients, production procedures, ambient conditions and construction practices.

Another approach to concrete cracking involves repairing existing concrete structures. Neptune Research Inc. (NRI; Riviera Beach, Fla.; www.neptuneresearch.com) recently introduced a composite product designed to repair existing concrete. Titan 118 combines a unique, uni-axial carbon-fiber fabric that is saturated with NRI's proprietary epoxy resin. Titan 118 is highly chemically resistant and can be applied at relatively high temperatures, says Eri Vokshi, a civil engineer at NRI. She points out that the International Concrete Repair Institute and ACI recently issued the first building code for concrete repair. The industry standard ACI-562 was revised to include the use of composites for repairs due to design errors, deterioration (due to corrosion and environmental factors), and change-of-use cases, she explains. In June, Titan completed a testing process to become certified by ICC Evaluation Service (www.icc-es.org), a non-profit testing organization, Vokshi says.

Alongside efforts to prevent and repair concrete cracks are those, mostly pre-commercial so far, to develop concrete capable of repairing its own cracks to prevent propagation. For example, Henk Jonkers, a researcher at the Delft University of Technology (the Netherlands; www.tudelft.nl), is leading a team working on concrete with self-healing properties. The team has found a way to embed calcite-precipitating bacteria into the concrete mixture. Jonkers has identified species of alkaliphilic bacteria that survive in the high-pH conditions in concrete. The bacteria produce calcite, a form of $CaCO_3$ that forms a solid to bridge developing concrete cracks.

Self-healing concrete could lead to substantial savings in steel-reinforced concrete, by offering a potentially economic way to address concrete durability issues, especially in areas that are difficult to repair by humans, such as underground hazardous waste retainers.

Concrete application

A number of new approaches in concrete technology are aimed at the way concrete is applied at a construction site. For example, WR Grace is developing rheology-modifying polymer additives for concrete. The V-MAR3

Concrete basics

Concrete exhibits a host of qualities that explain why it is the world's most used human-made material. Here are some basic facts and definitions surrounding concrete:

Concrete components: Concrete is a composite material that typically consists of gravel and crushed rock — known as coarse aggregate — sand, cement, water and air. Although there are many types of concrete, each resulting from a different blend of materials, a typical concrete makeup consists of the following (Figure 1): coarse aggregate (gravel, rock, crushed recycled concrete) — 41%; fine aggregate (sand) — 26%; cement — 11%; air (often intentionally entrained to provide resistance to freeze-thaw cycles that can lead to breakdown of material over time) — 6%; water (essential for hydration of cement) — 16%; additives (can control concrete properties, such as flowability, setting time and others — 1%.

Cement Compound	Weight Percentage	Chemical Formula
Tricalcium silicate (alite)	50 %	Ca_3SiO_5 or $3CaO{\cdot}SiO_2$
Dicalcium silicate (belite)	25 %	Ca_2SiO_4 or $2CaO{\cdot}SiO_2$
Tricalcium aluminate	10 %	$Ca_3Al_2O_6$ or $3CaO{\cdot}Al_2O_3$
Tetracalcium aluminoferrite	10 %	$Ca_4Al_2Fe_2O_{10}$ or $4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$
Gypsum (added to ground clinker)	5 %	$CaSO_4.2H_2O$

Cement raw materials: Ordinary portland cement was named after the Isle of Portland (off the British coast) by its inventor, stonemason Joseph Aspdin in 1824. Modern portland cement is the most common type for general use, and is a component of concrete, stucco and mortar. Portland cement is made from a proportioned blend of the following raw materials: $CaCO_3$ from limestone, chalk, shells, shale or calcareous rock; SiO_2 (silica), usually from sand, clay, old bottles or argillaceous rock; Al_2O_3 (alumina), usually from bauxite, recycled aluminum or clay; Fe_2O_3, (iron oxide) from clay, iron ore, scrap iron or flyash; $CaSO_4 \cdot 2H_2O$ (gypsum), usually found with limestone.

Cement manufacturing process: The solid raw materials (excluding gypsum) are ground and fed into large steel rotary kilns lined with special firebrick. The long, cylindrical kilns are angled downward and rotated to allow the raw materials to move through the kiln. Rotary kilns are equipped with heaters at the lower end that heat the material to 2,700°F. As a result of heating, the raw materials undergo a dehydration stage, where free water is driven off, followed by a calcining stage in which bound water and CO_2 are driven off. As the heat increases, a final sintering process occurs to form calcium silicates. The grayish, anhydrous pellets resulting from the process are known as clinker and are cooled upon exiting the kiln. The clinker (see table) is pulverized into the fine powder that is commonly called cement. Gypsum is added to the ground clinker to help control the time the cement takes to set.

Energy consumption has fallen drastically in cement manufacturing in recent decades. A state-of-the-art dry kiln equipped with a pre-calciner consumes 50% less energy than the long wet kilns that dominated cement manufacture in the past, Lafarge's Buffenbarger says. Further, more alternative fuels are being used to heat cement kilns, including biomass and waste materials, she adds.

Hydration chemistry: When water is added to a cement paste or a concrete blend with cement and aggregate materials, the cement minerals dissolve, forming an ionic solution. When the ionic species become supersaturated, a precipitation process occurs, where new solid species form. This dissolution-precipitation process allows the complex hydration reactions to occur and cause the cement to harden. Cement does not harden by drying; it sets due to the chemical hydration reactions. Hydration involves the formation of chemical bonds between water and the major compounds in cement. The main reaction products include the following: Calcium silicate hydrate (a major source of concrete strength) and calcium hydroxide (formed by alite hydration).

additive promotes improved flowability of concrete while preventing the segregation of gravel from the wet concrete slurry. "The rocks don't sink to the bottom," says Grace's Myers, and the concrete will self-level without segregation, saving jobsite labor."

Another approach is to introduce substances that catalyze the specific hydration reactions that impart strength to the hardened concrete. An example comes from Grace Construction Products, which has introduced a set of patented alkanolamine catalysts added to cement to accelerate specific chemical reactions that help develop strength in concrete, Grace's Myers says. The catalyst forms a reversible complex with iron, transporting the insoluble iron from the cement grain surface, where it impedes reaction of the strength-giving silicate phases. Catalyst dosages as low as 200 ppm in the cement can generate 10–20% strength improvements, Myers says.

Grace is also test-marketing Verifi, a product that allows a concrete truck's mixer to act as a rheometer. Using wireless communication and specially designed algorithms, the Verifi system sets up a feedback loop that controls the addition of water and additives to the concrete mixture based on the realtime rheological profile of the concrete in the transport truck, ensuring that the concrete arrives at a jobsite with the desired properties.

Molecular analysis

The Massachusetts Institute of Technology (MIT; Cambridge, Mass.; www.mit.edu) Concrete Sustainability Hub (CSHub) is a team of interdisciplinary researchers that has been investigating questions about concrete infrastructure science, engineering and economics for the past six years. Among the CSHub's most recent work is what MIT calls the "most detailed molecular analysis to date of the complex structure of concrete." The new analysis suggests that reducing the ratio of calcium to silicate in cement would not only cut CO_2 emissions, but would actually produce better, stronger concrete. The findings are described in the journal *Nature Communications* by MIT senior research scientist Roland Pellenq and others.

In conventional cements, Pellenq explains, the calcium-to-silica ratio ranges anywhere from about 1.2 to 2.2, with 1.7 accepted as the standard. But the resulting molecular structures have never been compared in detail. Pellenq and his colleagues built a database of all these chemical formulations, finding that the optimum mixture was not the one typically used today, but rather a ratio of about 1.5.

As the ratio varies, he says, the molecular structure of the hardened material progresses from a tightly ordered crystalline structure to a disordered glassy structure. They found the ratio of 1.5 parts calcium for every one part silica allows the material to achieve "two times the resistance of normal cement, in mechanical resistance to fracture, with some molecular-scale design." ■

Scott Jenkins

For more on concrete technology, see the online version of this article at www.chemengonline.com.

Improve Efficiency with Better Evaporation and Drying

For every application, there's an evaporator or dryer that can boost performance

IN BRIEF

ADVANCES IN EVAPORATION

DRYERS FOR EVERY APPLICATION

In today's economy, chemical processors must deliver high product quality and uniformity while maintaining high yield and low production costs in order to be successful. For this reason, they depend upon efficient continuous evaporation and drying processes for the production of high-quality products with specific product parameters. There's a plethora of evaporation and drying equipment engineered to meet the needs of the chemical process industries (CPI), in the most cost-effective, process-efficient and energy-saving way possible.

Advances in evaporation

The ideal choice of evaporation technology depends upon factors such as viscosity and the thermal characteristics of the product, the required output rate and the available energy supply, according to Niels Knudsen, sales manager, Flow Food and Beverage, SPX Flow Technology (Søborg, Denmark; www.spx.com). Evaporation techniques include single pass or circulation, single or multiple effect and thermal or mechanical vapor recompression, he says. The proper evaporator must be selected for the product being processed, as well as for the specific challenges associated with that product or process.

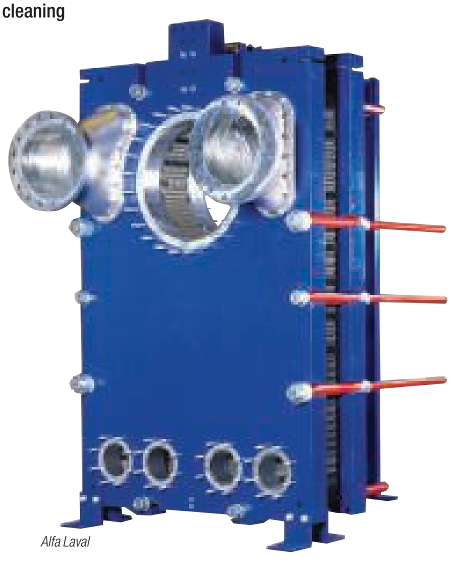
"For example, for concentration of low- to medium-viscosity organic and inorganic products, falling film evaporation is widely applied," he says. "SPX's Anhydro brand falling film evaporators deliver low energy consumption, high heat-transfer coefficients and a single-pass evaporation that yields a short residence time for minimum impact on product quality."

In addition to direct steam heating, Anhydro falling film evaporators apply two vapor-recompression techniques to minimize the energy consumption: mechanical vapor recompression (MVR) and thermal vapor recompression (TVR). MVR requires little or no steam and delivers substantial operational cost savings in areas with an ample supply of low-cost electricity. For TVR, multi-effect evaporation uses vapor from one effect as the heating medium in a subsequent effect, thereby operating at a lower pressure and temperature.

For difficult and demanding tasks in the fields of distillation, concentration and degassing, thin-film evaporators can be applied, says Rainer Fabricius, sales manager with Buss-SMS-Canzler (Düren, Germany; www.sms-vt.com). Gentle handling of the product using short residence time and high evaporation ratios in a single pass, as well as minimal loss during product change due to low holdup, make them ideal for these applications. In addition, the availability of different rotor types, vertical or horizontal designs and cylindrical or conical designs provide flexibility. Buss-SMS-Canzler also offers a computational fluid dynamics (CFD) software tool that calculates the liquid and vapor flow in thin-film evaporators, including heat and mass transfer. "This detailed knowledge about the processes taking place within the evaporators creates the foundation for new developments of thin-film evaporators and their adaptation to new applications," notes Fabricius.

In evaporation processes where fouling may be an issue, Anders Gidner, marketing manager, Life Sciences and Renewable Resources with Alfa Laval Inc. (Lund, Sweden; www.alfalaval.com), recommends a different type of technology. "Fouling has always been a problem with any evaporation application, but it's even more challenging in some of the second-generation chemical plants for ethanol production or those processing products with an industrial fermentation step," says Gidner. "One of the biggest problems in processes that are subject to fouling occurs when concentration increases, so it is very

FIGURE 1. The AlfaVap plate evaporator consists of a plate pack with alternating welded channels and traditional gasketed channels. All plate surfaces in the gasketed channels are easily accessible for inspection and manual cleaning



Alfa Laval

Powder Systems Limited

FIGURE 2. The Agitated Nutsche Filter Dryer allows the user to control and optimize the isolation by filtering out a maximum of the solvent using pressure and heated agitator blades to bring down the moisture content

SPX

FIGURE 3. High- and low-viscosity liquids and heat-sensitive products should be spray dried because it is a continuous process, converting a pumpable liquid into a particulate matter in a single operation via spray dryers such as the Anhydro spray dryer shown here

important that the process operates in a way that avoids high temperatures, long residence times or other troublesome characteristics."

For this reason, Gidner recommends moving away from traditional shell-and-tube evaporators in fouling-prone or other applications where shorter residence times are desired for other reasons. He suggests the use of a plate evaporator, such as the AlfaVap (Figure 1). This plate evaporator consists of a plate pack with alternating welded channels and traditional gasketed channels. A frame holds up the plate pack, clamps it together and provides a connection with the piping system. The frame consists of two heavy covers of painted carbon steel between which the plate pack is pressed together by means of tightening bolts.

The frame plate is stationary while the pressure plate is movable along the carrying bar, which also holds the plate pack. The carrying bar is supported by the frame at one end and a support column at the other, which are bolted to the foundation.

This design, according to Gidner, provides higher thermal efficiency than traditional evaporators and condensers, which means less heat-transfer area is needed to achieve any specific effect. In addition, the special corrugated patterns of the heat-transfer plates create a high degree of turbulence over the entire surface of each plate, which helps prevent fouling. The design of the unit also makes it easy to adjust evaporation and condensation capacity to meet changing needs, simply by adding or removing plates to the existing frame.

Dryers for every application

In drying processes as well, process efficiency, energy efficiency and product quality remain major issues. As such, drying equipment, like evaporation technology, should be chosen according to the specific application being processed, as well as associated needs or challenges. Fortunately, there are as many different types of drying technologies available as there are applications.

For example, when it comes to drying crystalline active pharmaceutical ingredients (APIs), ensuring stable, consistent and free-flowing materials for formulation, storage, packaging and transport is important. For this reason, stringent monitoring is needed to control the drying temperature ranges and optimize the drying efficiency while keeping the product stable. "There are risks of decomposition, melting or agglomeration if not handled properly," says Christian Parker, head of engineering with Powder Systems Ltd. (PSL; Liverpool, U.K.; www.powdersystems.com).

The solution, he says, is to consider the drying process as an integrated process with crystallization or precipitation and isolation. "How these steps are being performed will directly impact the efficiency of the drying operation from the particle-size distribution to the remaining moisture level. If solvent has been removed efficiently beforehand, process efficiency will be easier to achieve," he explains.

New isolation technologies have helped to provide better efficiency. Conductive dryers where materials are in direct contact with the heated surface provide energy efficiency and shorter drying times. Gas is often circulated to carry off the evaporated solvent. Reduced pressure, up to full vacuum, is used to increase efficiency and avoid explosion risks when using flammable solvents.

To provide better efficiency, Parker continues, drying technologies have evolved to provide greater effective surface area that reduces drying times. This is the case with agitated dryers, because the wet cake is bet-


a better way to view
LEVEL
6
3
in.
0
ORION
INSTRUMENTS
316 SS Construction
IP66/68
2x
ORION
140°
viewing angle
+ 200 ft. (60 m)
ASME
U
ORION®
INSTRUMENTS
A Magnetrol® Company
orioninstruments.com
High-visibility level indicators and transmitters from Orion Instruments are custom-engineered and built tough for the most demanding applications. Contact us to find out how personnel safety, cost of ownership, and reliability can all be improved over traditional sight glass gauges.
Circle 29 on p. 94 or go to adlinks.chemengonline.com/56201-29

ter exposed for heating and drying. Agitation can reduce cycle time by speeding evaporation operation and provide better product quality, avoiding biscuit-effect or crust to form on the cake, says Parker.

"Combining the isolation and drying steps has been one of the major innovations of the last century for chemical processors," he continues. The Agitated Nutsche Filter Dryer (ANFD; Figure 2) is an example of this technology. It allows the user to control and optimize the isolation by filtering out most of the solvent using pressure and heated agitator blades to bring down the moisture content. Then, within the same vessel, drying is achieved under vacuum via heat transfer and direct contact with the heated jacket, plate and, in some cases, the agitator as well. "Agitation is an important part of an efficient drying process," says Parker.

High- and low-viscosity liquids and heat-sensitive products have a different set of concerns, according to SPX's Knudsen. "These products are usually spray dried because it is a continuous process, converting a pumpable liquid into a particulate matter (Figure 3) in a single operation," he says. The liquid is atomized into very fine droplets in a drying chamber, where evaporation takes place by contact with hot air and a powder is formed. The powder is separated from the drying air in a cyclone or bag filter system.

"At the heart of this process is the atomizer," says Knudsen. SPX offers two basic types of atomizers. Centrifugal atomizers accelerate and atomize the liquid feed using centrifugal force in a spinning disc, which is suitable for many chemical applications. Nozzle atomizers spray the liquid feed under high pressure or using compressed air, which is particularly effective when a coarse powder with narrow particle-size distribution and high bulk density are required.

Similarly, biomass as a feedstock has its own special requirements, which can be properly addressed using rotary dryers, according to Becky Long, dryer design engineer with Thompson Dehydrating Co. (Topeka, Kan.; www.thompsondryers.com). A rotary dryer features a rotating cylindrical drum, which acts as a container for the uniform transfer of thermal energy from a hot gas stream to a moisture-laden product, such as biomass, for the purpose of moisture reduction in the product. Wet product is introduced into the inlet of the drum, where it is dried as it is conveyed to the drum's outlet. The drum is equipped with flighting to disperse the product into the drying gas stream as the drum rotates.

It is the flighting, and its ability to adapt to new purposes, according to Long, that makes rotary dryers a suitable choice for biomass processing. Flighting is the primary material handling mechanism in a drum. And Thompson designs its flighting to be easily changed to provide flexibility. "In the biomass industry, there is such a variety in the materials being processed that it can change from year to year, so we need the ability to alter the flighting system if the feedstock

Witte

FIGURE 4. Witte's air-operated gates rotate 90 degrees above the deck on a cycle timer, allowing a pre-determined amount of product to advance, providing the operator with flexibility and realtime control over the flow and retention time

changes," notes Stan Thompson, dryer design engineer with Thompson. "We also realized that people may need to change the capacity, which means that some of our rotary material techniques that work well for one capacity need to be altered for another, so we make our flighting bolt-in, making it easier to change than flighting that is welded-in."

Since different flighting designs are key to solving problems associated with a range of feedstocks, a flighting designer, with access to easily changed flighting systems, can examine the flow characteristics of the new feedstock and convert the dryer to suit a new purpose at a fraction of the cost of buying a new dryer, notes Long.

And for general drying applications that demand uniform flow, vibrating fluidized-bed dryers with advanced vertical air-flow engineering may be a solution, according to Larry Stoma, design engineer with Witte (Washington, N.J.; www.witte.com). The vertical air flow, he says, can make the drying process much more efficient. Angled air that flows at slightly more or less than 90 deg creates dead spaces in the fluidized bed where drying is weak and hot spots where drying is too strong, which can lead to uneven product flow, charring, clogging and other issues. But, in a Witte vibrating fluidized-bed dryer, air flows vertically, perpendicular to the fluid bed deck and at a constant velocity, ensuring uniform heat history through the entire length of the system. The result is a thin layer of product in contact with the air flowing evenly from feed to discharge, with the first product in as the first product out.

In addition, features such as automatic weirs provide more control of retention time without product degradation (Figure 4). "We found that as material travels through the dryer, it sometimes builds up in the dams along the length of the dryer," explains Stoma. "Heat-sensitive materials, if stuck, can become overheated and discolored. So, we designed a system where each of the dams along the length of the dryer is raised on a time cycle. This allows any material trapped in the front of the dams to move on, providing very uniform flow through the dryer."

He adds that in addition to providing uniform flow, the auto weirs provide an effective way to adjust the residence time in the dryer. "We can adjust the open time and down time of the weirs, which allows users to adjust the residence time for the specific product," he says. ■

Joy LePree

Software and Mobile Apps

SKF USA

Workrite Uniform

Eriez

GTI Predictive Technology

Mobile app and vibration sensors monitor machinery

The SKF Enlight platform combines a new mobile app with a Bluetooth-enabled vibration sensor to enable staff to collect machinery data with no special training (photo). This allows standard mobile devices, such as smartphones or tablets, to function as data-collection devices to gather critical machinery data. In the event of a parameter warning or alert, the user can then request an "on-demand diagnostic," whereby the data are sent wirelessly to the SKF Remote Diagnostic Center network, for expert analysis and reporting. This approach offers a user-friendly alternative to dedicated, high-end vibration analyzers that require a high level of staff competence and are particularly expensive for one-off data measurements, says the company. For data collection in hazardous areas, specially built and intrinsically safe ATEX Zone 1-compliant smartphones and tablets can be used. The SKF Wireless Machine Condition Detector (WMCD) is a sensor that mounts magnetically to a machine and measures vibration data. It takes a simultaneous measurement of bearing condition using patented SKF algorithms to assess the severity of any damage or wear.— *SKF USA Inc., Lansdale, Pa.*
www.skfusa.com

This app eases the process of evaluating protective clothing

The FR Clothing smartphone app (photo) provides easy access to key information about flame-resistant (FR) workwear for plant personnel, including information about hazards, safety standards, flame-resistant clothing brands, product lines from several leading vendors and more. The menu allows users to select information based on categories, including hazards such as flash fire, electric arc, molten-metal splatter and fire service. The app also gives users the option to select information by industry, such as oil-and-gas drilling and refining, welding, combustible dust, fire service and more. Additional support tools are provided in the FR Essentials section, which allows users to look up terms in the FR dictionary, watch educational videos, learn more about FR fabric usage and care, read posts in the "Tech Notes" blog, and learn more on temperature ratings. Additional technical content is provided through a frequently asked questions (FAQ) section. — *Workrite Uniform, Oxnard, Calif.*
www.workrite.com

Free programs help improve the design of vibratory systems

This company has developed two free, downloadable programs to simplify the process of determining the proper vibratory equipment for different applications. The Feeder Tray Capacity Calculator (photo) determines the appropriate tray size based on the material being fed and the desired flowrate. The Bin Guide selects the proper bin vibrator, again, based on the material being fed, desired feed rate and size of the hopper. As the dimensional information is entered, the Bin Guide presents a three-dimensional sketch of the bin geometry. The program offers a complete library of material densities, allowing users to access this information easily. — *Eriez, Erie, Pa.*
www.eriez.com

Vibration-monitoring system builds on iPad capabilities

The VibeRMS LT is an affordable condition-documentation solution for the iPad. This single-channel, vibration-documentation tool lets users view live vibration data (velocity, acceleration, displacement) and create reports at the site using an iPad (photo). Reports can be generated to describe machine data, spectrum data, alerts and alarms, user notes and integrated photos. The Machine Build function includes templates for common machine types (such as motors, pumps and fans), and gives users the ability to combine machine types to create machine-train

Note: For more information, circle the 3-digit number on p. 94, or use the website designation.

templates. Such templates can be built onsite using a photograph of the machine. Measurement points are added by the user to complete the template. VibeRMS is designed to take advantage of the iPad's inherent value-added functions, such as its camera, touchscreen capabilities and email access (to allow reports to be shared).— *GTI Predictive Technology, Manchester, N.H.*
www.gtipredictive.com


Phoenix Contact

Tablet PCs for portable use, both indoors and outdoors

Modern industrial networks increasingly require mobile workflows and remote-controlled processes. The new Industrial Tablet Computer (ITC) 8113 has improved processor performance and luminous Full HD display (photo). It offers comprehensive accessories and is optimized for use in a service environment. For wireless connection to an existing network, wireless communication is possible via WLAN 802.11 a/g/n, Bluetooth 2.0 Class 1 and Class 2, and a UMTS/LTE data communication module is optionally available. —*Phoenix Contact GmbH & Co. KG, Blomberg, Germany*
www.phoenixcontact.com

Use this app to get snapshot of tank emissions

This company's Tank Emissions app is available for iOS devices (including the iPhone and iPad). It allows users to estimate whether their systems are within permit limits, or if it is time for a qualified engineer to evaluate the tank and related system. Based on data from the U.S. Environmental Protection Agency's AP 42 air pollutant emissions standard, the app simplifies a very complex set of calculations in order to give the user a rough estimate of the tank emissions. The results are not intended to be used officially; rather they provide guidance to help the user plan a path forward, says the company. —*Halker Consulting, Englewood, Colo.*
www.halker.com

Get easy access to regulatory-compliance information

Ariel WebInsight Mobile offers instant access to chemical regulatory-compliance reference data, using a smartphone or tablet. Comprehensive, centralized global regulatory information is now available for portable viewing, thereby saving time and hassle, and promoting product and facility compliance. It provides an intuitive user interface to access environmental, health and safety (EH&S) compliance resources to help users perform such functions as validating that products can be sold in their intended markets, ensuring that safety data sheets and labels are compliant, identifying regulatory authorities that require notification for import and export, and knowing which agencies to notify in the event of a chemical release or spill. — *3E Company, Carlsbad, Calif.*

This app makes it easy to review safety scenarios

The Total Safety Industrial Safety Moments app offers a compliance- and training-oriented approach, allowing users to share "safety moments" easily from any mobile device. The developers applied more than 20 years of safety experience to develop real-world, relevant topical overviews and conversation starters. Each scenario described includes links to the relevant regulatory requirements, making it easy for users to access and share critical information. Users can search by industry, or by an array of safety categories (such as gas detection, emergency rescue, fire prevention, respiratory protection, industrial hygiene and more). — *Total Safety, Houston*

www.totalsafety.com

Improve the utility of, and access to, laser-scan projects

The co-launch of LFM NetView 4.0 and LFM Server 4.3 provides capability improvements for CPI professionals who use laser-scan technology to enhance project collaboration and asset management. Specifically, the introduction of new three-dimensional mark-up functionality to both products allows users to add, access, and share asset intelligence in the form of tag identifiers, attributes and comments, as well as links to associated documents and information. Along with these new capabilities comes improved access to massive laser-scan projects, supported by cloud and tablet enablement. These deliver the "as-operated" asset conditions to the desktop and mobile devices of all asset stakeholders, allowing for secure global collaboration across multiple project teams and partner companies, says the firm. — *LFM Software, Manchester, U.K.*

www.lfmsoftware.com

App improves temperature-logging capabilities

The Cyclops Logger App enhances the operation of the company's Cyclops portable infrared-based, non-contact thermometer (photo). It features a Route Mode management system, which ensures that temperature measurements are recorded at pre-configured locations. The information can be presented against a variety of parameters, such as emissivity and window correction. This provides configurable measurement

Ametek

routes for the plant or process, making it ideal for monitoring areas with multiple locations that require regular monitoring, says the company. A four-digit code assigned to each temperature reading along the route allows predefined information about the material's emissivity to be linked to every measurement location, and date and time data to be captured. Once the user has taken temperature measurements, and the data have been recorded automatically by the new Cyclops Logger app, the data can be downloaded using the Bluetooth capability to a desktop computer for sharing or analysis. — *Ametek, Land Instruments International Ltd., Dronfield, U.K.*
www.landinst.com

Keep an eye on the condition of rotating equipment

The iAlert2 machine-health, condition-monitoring device and mobile app uses Bluetooth Smart technology to identify potential operating problems before they become costly failures. The app helps track and report early warning signals from rotating equipment. The i-Alert2 tracks vibration, temperature and run-time hours, and wirelessly syncs the data with a smartphone or tablet. The device povides early detection of system failures with realtime machine records and data logging with trend analysis. It is rated for use in hazardous environments with potentially explosive gases, dusts and fibers. It is engineered and rated for use in a wide range of industrial environments, and is chemical-resistant and is rated for extreme temperatures (–40 to 84°C). Through the mobile app, users can view realtime and historical data, diagnostic information and machine records. — *ITT Corp. White Plains, N.Y.*
www.itt.com

Evaluate your options for severe-service valves

ValveTechlopedia is a new app that gives users access to information about industry applications that require zero-leakage, severe-service,

isolation valves (such as high-temperature, high-pressure, high-cycling applications that handle abrasive, corrosive and caustic media). The app provides detailed information on the company's products, a glossary of terms, conversion tables, information about valve-testing standards and coating options, access to sizing standards and a unit converter. The app, available for Android and Apple mobile devices, is designed to allow for offline browsing and viewing — *ValvTechnologies, Houston*
www.valv.com

Mobile app simplifies plastics selection

The interactive Plastic Selector Mobile App T helps users search for plastic materials to meet their application demands based on key performance specifications using their mobile devices. The app lets users compare up to five materials with similar properties. — *Gehr Plastics, Boothwyn, Pa.*
www.gehrplastics.com

Virtual chemistry set is available for the iPad

The ChemCrafter app is an educational tool that lets burgeoning chemists and chemical engineers build their own virtual laboratory to run experiments using an iPad. The Chem-o-converter functionality measures energy released and lets users gain points that unlock new experiments and access to additional equipment and chemicals. Embedded strategy guides lead the user through experiments with water, acids and salts, displaying results with visual color changes, fire and smoke simulations, gas releases and shattering equipment, where relevant. — *Chemical Heritage Foundation, Philadelphia, Pa.*
www.chemheritage.org

Simplify flow conversions by using this mobile app

This mobile app lets users take the drudgery out of flow conversions, right from their mobile devices. It allows users to convert one set of mass flow units to another, with just a few taps of the fingers. — *Teledyne Hastings Instruments, Hampton, Va.*
www.massflowconverter.com

A wealth of weighing information, at your fingertips

This company's Mobile Library app provides a diverse array of expert information for engineers who are interested in accessing information about weighing system design, operation and troubleshooting. The app features instructional videos, webinars, white papers and other technical guides, on topics ranging from load-cell technology and scale selection, to regulatory compliance and quality control. The app is available for Android and iOS operating systems. —*Mettler Toledo, Greifensee, Switzerland*
www.us.mt.com ■

Suzanne Shelley

PFA-lined gear pump for aggressive or high-purity liquids

Liquiflo Polygard Series pumps (photo) are perfluoroalkoxy-lined (PFA) magnet-drive gear pumps for moving challenging liquids, such as acids (including hydrochloric, sulfuric, hydrofluoric, nitric and chromic), ferric chloride and sodium hydroxide. These pumps feature non-metallic wetted parts and zero leakage. They are available in seven sizes in both DIN- and ANSI-flanged connections, and provide flows up to 47 L/min at differential pressures up to 7 bars, and they can operate at temperatures up to 90°C. PFA-lined stainless-steel housings for these pumps do not suffer from the wicking problems associated with fiber-reinforced housings, and the effects of heat entrapment and corresponding thermal expansion are minimized, says the company. — *Michael Smith Engineers Ltd., Woking, U.K.*
www.michael-smith-engineers.co.uk

A new series of screw pumps for multiphase-fluid applications

This company has introduced the new S Series of screw pumps (photo) for conveying challenging fluids. These rotary positive-displacement pumps are ATEX-certified for use in explosive or dangerous environments. They are self-priming, and deliver a constant flow with low pulsations, even at considerably different pressures and volumes, says the manufacturer. Twin-screw pumps can be a good option for conveying challenging multiple-phase fluids containing oil, gas and water. In a variant of the S Series, the twin-screw pumps employ timing gears to transmit the power from the power screw shaft to the idler screw shaft to reduce the possibility of wear when pumping abrasive materials, or where special materials of construction dictate non-contacting operation. — *Maag Industrial Pumps, Oberglatt, Switzerland*
www.maag.com

Variable-speed converters deliver benefits for moving natural gas

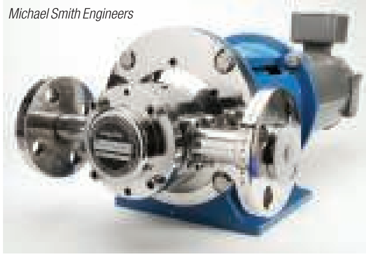
The Vorecon with Dual Torque Converter (photo) is a variable-speed planetary gear with two matched torque converters. It delivers high efficiency, even into the lower speed range, providing an efficient way to control the speed of large pumps and compressors in a variety of fields. It is up to 2% more efficient than variable frequency drives (VFDs), says the company. The patented Vorecon with Dual Torque Converter is expanding its footprint in the U.S. market, with five Vorecons equipped in compressor stations transporting natural gas from the Marcellus shale formation into markets in the mid-Atlantic and Southeast states. These Vorecons are increasing transport capacity by over 25%, and improving reliability and efficiency in the process, says the manufacturer. — *Voith Turbo GmbH & Co. KG, Heidenheim, Germany*
www.voith.com

Fluoropolymer sensors extend this temperature logger's range

The TR-71nw two-channel temperature-data logger (photo) supports automated data collection, remote monitoring and alerting with a simple Ethernet LAN connection. Data can be automatically uploaded to a Web-based storage service, and alerts can be sent via email. Alternatively, all data can be accessed through dedicated mobile applications, available for both Apple iOS and Android platforms. The TR-71nw measurement range is –40 to 110°C (with the standard supplied sensor), and an expanded range of –60 to 155°C is available with an optional fluoropolymer-coated sensor. — *TandD Corp., Santa Fe, N. Mex.*
www.tandd.com

Two new gas regulators to control and relieve pressure

This new series of highly durable specialized gas regulators (photo) is designed to provide accurate control of systems operating under vacuum. The EXS Sub-Atmospheric series regulator provides precise control under sub-atmospheric conditions, along with low setpoint and low-flow, positive-pressure applications. Its proprietary hybrid-spring design works in tandem with an oversized dual-surface diaphragm to enable sensitive control, in contrast to a standard regulator design that loses the ability to control pressure when subject to downstream vacuum, says the manufacturer. The EXZ Sub-Atmospheric series backpressure regula-


Michael Smith Engineers


Maag Industrial Pumps


Voith Turbo

TandD


AURA Gas Controls

HPC Compressed Air Systems

AUMA Riester

Intertec Instrumentation

Banner Engineering

tor provides repeatable relief of excess positive pressure caused by accumulation or upstream sample injection in systems operating under vacuum. Its high-load adjusting spring maintains seat closure under vacuum, while a negative bias-spring allows for precise relief as positive pressure is introduced. This enables the user to accurately throttle excess positive pressure from the system. — *AURA Gas Controls, Virginia Beach, Va.*
www.auracontrols.com

Save energy and space with these compact refrigerant dryers

Efficient and reliable compressed air treatment, such as refrigeration drying that removes unwanted moisture, is essential in many industrial applications, and the new Secotec TF Refrigerant Dryer Series enables users to maximize energy savings while using less space. A feature of these second-generation dryers is a latent-heat, thermal-mass heat-exchanger system, which leads to a significantly higher thermal storage capacity, as 98% less thermal material is required compared to conventional refrigeration-drying systems. The dryers deliver air flows from 17 to 34 m^3/min, and are designed to use less than 87 W/m^3 of air to be dried per minute, compared to conventional systems that use 200–250 W/m^3 on average, says the company. — *HPC Compressed Air Systems, Burgess Hill, U.K.*
www.hpccompressors.co.uk

A new range of coaxial-valve gearboxes

The new GP range of coaxial gearboxes allows manual valve operation or automation via an actuator, that is mounted by means of an adapter flange. The illustrated versions (photo) are equipped with handwheel and square for power-tool operation. GP gearboxes can be used to operate gate and globe valves, but also partial-turn valves like butterfly valves and ball valves. Coaxial design allows centered gearbox mounting onto valve flange and avoids radial force impact to the valve. The gearboxes are available in four sizes with three reduction ratios each, and cover the torque range between 100 and 2,500 N-m. Reduction ratios are implemented by planetary gearings. — *AUMA Riester GmbH & Co. KG, Muellheim, Germany*
www.auma.com

This triple diaphragm pump's gears are arranged in 3D

The Novaplex Vector is a triple-diaphragm process pump that reduces the required footprint for installation by arranging the pump heads in three dimensions. Its new patented design simplifies assembly and reduces the number of crankshaft bearings from six to two, increasing reliability and making maintenance easy. The model uses the robust Bran+Luebbe diaphragm-pump head design, which can be used in potentially hazardous atmospheres, and is certified for use in hazardous areas up to Zone 1 IIC T4. The pump can be equipped with the Novalink-CSM 2 continuous pump-monitoring system. This software can be used as a stand-alone solution or incorporated into an asset-management system to enable advance detection of possible pump failure. Its use can help to optimize maintenance schedules. — *SPX Corp., Charlotte, N.C.*
www.spx.com

Explosion-proof HVAC system for process analyzer shelters

This ATEX-compliant HVAC (heating, ventilation and air-conditioning) system (photo) provides a complete all-in-one climate-control and personnel-safety solution for walk-in style process-analytical instrumentation shelters. It is customizable and scaleable to suit a broad range of applications, and can be supplied fully integrated within the shelter or as an external standalone unit. Designed specifically for hazardous-area applications up to Zone 1, the system delivers a steady flow of conditioned and filtered clean air to the shelter, maintaining it slightly above atmospheric pressure to prevent the ingress of dust or gas. It is especially suitable in plants that operate in extremely hot or cold climates, or where atmospheric contaminants pose safety, health or corrosion issues with conventional through-flow air-conditioning systems. — *Intertec Instrumentation Ltd., Sarnia, Ont., Canada.*
www.intertec.info

This laser-distance sensor includes updated firmware

This company's Q4X laser-distance sensor (photo) has been updated to include a new dual-teach-mode model. Featuring new firmware, the Q4X dual-

teach-mode sensor combines window thresholds on both target distance and target reflected intensity, and can now detect clear objects without requiring a retro-reflector. The Q4X detects distance changes as small as 1 mm, and covers a range from 25 to 300 mm. The sensor is suitable for difficult distance-based sensing applications, as it can detect objects regardless of target surface reflectivity, including black foam on black plastic, black rubber in front of metal and multicolor packaging. With the dual-teach mode, the sensor can now detect small changes in reflected intensity for targets inside the distance threshold. — *Banner Engineering, Minneapolis, Minn.*
www.bannerengineering.com

A TDL gas analyzer designed specifically for ammonia

The Servotough MiniLaser Ammonia (photo) is said to be the world's smallest cross-stack tunable-diode laser (TDL) gas analyzer, and the only TDL analyzer specifically optimized for ammonia gas measurement. Optimized for the fast, accurate and responsive measurement of ammonia in hot or hazardous conditions, the Servotough MiniLaser Ammonia is particularly suitable for ammonia slippage applications in coal-fired power plants. The MiniLaser's compact size and dramatically reduced footprint offer installation flexibility. A built-in display eliminates the need to use a laptop for configuration and diagnostics. The MiniLaser Ammonia also includes a new purge design, which significantly reduces nitrogen and air purge costs. — *Servomex Group Ltd., Crowborough, U.K.*
www.servomex.com

Servomex Group

Ironless motors provide smooth motion and a high velocity range

The compact V-551 motorized linear-translation stage comes equipped with an integrated absolute-measuring encoder with a resolution of 2 nm. High velocity (up to 500 mm/s) and quick acceleration are provided by a newly developed ironless magnetic linear motor, resulting in high accuracy and smooth motion. Precision-crossed roller bearings with anti-creep cage assist provide accurate guiding. The ironless non-cogging linear motors provide very smooth motion, and a high dynamic velocity range, along with rapid acceleration. They are suitable for applications where high or extremely constant velocity is required, such as in optics inspection, metrology, photonics and interferometry. — *PI (Physik Instrumente) L.P., Auburn, Mass.*
www.pi-usa.us

Energy-efficient induction motors for use with VFDs

The Large AC-GPM line of energy-efficient foot-mounted induction motors (photo) includes custom models ranging from 250 to 1,500 hp. The GPM product line fits various industrial applications where high torque is required, including pumps, fans, conveyors and compressors. Stock GPM motor features include all cast-iron construction, drive-end slinger, insulated opposite drive-end bearings, space heaters, and a ground lug in the conduit box. The entire product line is suitable for use with VFDs. — *Baldor Electric Co., Fort Smith, Ark.*
www.baldor.com


Baldor Electric

Expanded compatibility for this boiler-control system

This company has expanded its patented Temp-a-Trim control system (photo) so that it is compatible for installation on any brand of commercial or industrial boiler. The Temp-a-Trim system is designed to deliver fuel savings of up to 3% and electrical savings of up to 30% in boilers, says the company. Temp-A-Trim works by precisely correcting for air density, as the combustion air temperature changes to automatically optimize combustion efficiency. A built-in VFD adjusts the fan speed based on incoming air temperature to create a constant airflow for combustion, assuring that the burner is always operating at its maximum efficiency. — *Webster Combustion Technology LLC, Winfield, Kan.*
www.webster-engineering.com


Webster Combustion Technology

A control system with a pin-less electromagnetic backplane

This company has released a new industrial control system (photo) that features a patented architecture with a pin-less, electromagnetic backplane and embedded cybersecurity. According to the company, this


Bedrock Automation

Grundfos Pumps

Flowserve

system addresses virtually all control applications with fewer than a dozen part numbers, reducing cyberattack vectors, cutting lifecycle costs, and simplifying engineering, commissioning and maintenance. Furthermore, the system delivers input/output (I/O), power and communications across the pin-less electromagnetic backplane with a parallel architecture that supports fast scan times, regardless of I/O count. The removal of I/O pins improves reliability and increases cybersecurity, while forming a galvanic isolation barrier for every I/O channel. This backplane also allows for the installation of I/O modules in any orientation and location for flexibility in I/O and cable management. — *Bedrock Automation, San Jose, Calif.*
www.bedrockautomation.com

These wastewater pumps handle solids up to 4 in. in diameter

SL submersible wastewater pumps (photo) are designed to handle raw sewage, effluent and large volumes of surface and process water in municipal, utility and industrial applications. The solids-handing pump series, with motor ranges from 1.5 to 15 hp, is available with two types of impellers: the SLV SuperVortex Impeller and the SL1/S Tube Impeller. Both impeller types allow for the free passage of solids up to 4 in. in diameter, making them suitable for liquids with a content of solids, fibers or gassy sludge. The SL1/S pump type is designed particularly for large flows of raw sewage. — *Grundfos Pumps Corp., Downers Grove, Ill.*
www.us.grundfos.com

This low-consumption steam trap can be installed in any position

The Gestra BK37-5 thermostatic bimetallic steam trap (photo) does not consume live steam during operation and can save up to 0.9 kg/h of steam consumption when compared to thermodynamic and inverted-bucket steam-trap technologies, says the company. The BK37-5 is designed for pressures from 10 to 650 psi, and is suitable for both saturated and su-

perheated steam. Its normally open function allows for automatic air venting and high-ratio startup, and the trap's operation is unaffected by pipeline orientation, allowing it to be installed in any position. The BK37-5 also features the field-proven BK46 regulator, which is not affected by waterhammer or ambient conditions. — *Flowserve Corp., Irving, Tex.*
www.flowserve.com

Locally or remotely monitor the water content of recycled metals

This company's Smart Moisture Monitor (photo) is a non-contact electronic-scanning device that helps to prevent excessive water content in recycling processes to increase metals recovery. The Moisture Monitor measures the water content of material passing through its inspection field. When installed on a conveyor, it reports the moisture content of the material on the belt as a percentage that can be read locally or remotely via a Web portal. The device enables users to optimize the amount of water injected into the mill to prevent fires and control airborne dust generation. — *Eriez Manufacturing Co., Erie, Pa.*
www.eriez.com

Eriez Manufacturing

Backpressure regulators designed for CO_2 extraction

The BR series of backpressure regulators (photo) features a blockage-resistant design geared toward supercritical CO_2 extraction, as well as other processes in which clogging, blocking or freezing are potential problems. The BR series relies on internal passages to eliminate convergence points for the build-up of ice and high-viscosity oils. This design allows for precise backpressure regulation during processes involving gas expansion. BR devices are available for pressures up to 5,000 psi in standard trim, as well as pressure ranges up to 10,000 psi with high-pressure trim. — *Equilibar Precision Pressure Control, Fletcher N.C.*
www.equilibar.com ■

Equilibar Precision Pressure Control

Mary Page Bailey and Gerald Ondrey

Variable Frequency Drives

Department Editor: Scott Jenkins

Electric alternating current (a.c.) motors power all types of equipment in the chemical process industries (CPI), including pumps, fans, blowers, compressors and other types of process equipment. Electric motor systems offer opportunities for reductions in power consumption because while some applications require a constant motor speed, half of all electric-motor applications have a speed demand that varies with different conditions. In those situations, it is desirable to employ a variable frequency drive (VFD), also known as an adjustable speed drive, to achieve flexible process speed and torque, and thereby increase system efficiency. This one-page reference provides information on VFD operation and potential benefits.

VFD principles

A VFD is a type of motor controller that drives a.c. electric motors by varying the frequency and voltage supplied to the electric motor. Electrical frequency (Hertz) is directly related to the motor's speed (revolutions per minute; rpm), so higher frequencies translate into higher motor rpm. VFDs convert an incoming electrical supply with fixed frequency and voltage into a variable frequency and variable voltage output for the electric motor (Figure 1). This allows motor speed to be varied from 0 rpm to typically 100–120% of its full rated speed, while up to 150% of rated torque can be achieved at reduced speed.

VFDs exhibit high versatility and are available in a range of capacity sizes, from 0.2 kW to several megawatts. They are usually available as stand-alone devices and are connected to the motor's electrical supply. However, some smaller motor designs may have VFDs available as an integrated motor-drive product.

VFD components

Major components of a VFD include the following:

Rectifier. This converts incoming a.c. supply to direct current (d.c.).

Intermediate circuit. The rectified d.c supply is then conditioned in the intermediate circuit, most commonly by a combination of inductors and capacitors. Most currently available VFDs use a fixed-voltage d.c. link.

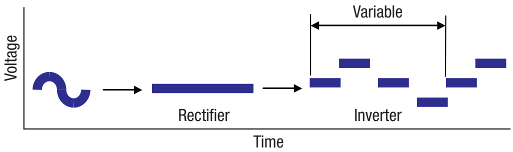


FIGURE 1. VFDs work by converting an incoming electrical supply from alternating current to direct current, then creating a variable-frequency alternating current that can be used to control motor speed

Inverter. The inverter converts the rectified and conditioned d.c. back into an a.c supply of variable frequency and voltage. This is normally achieved by generating a high-frequency pulse-width-modulated (PWM) signal for frequency and effective voltage. PWM is a modulation technique where the average value of voltage fed to the motor is controlled by switching power supply on and off at fast rates. The ratio between on and off periods determines the total power supplied to the motor, with longer off periods associated with lower motor speeds. The high on-off frequency allows the motor to perceive a smooth power supply. Semiconductor switches are used to create the output.

Control unit. This controls the operation of the VFD by monitoring and controlling the rectifier, the intermediate circuit and the inverter to deliver the correct output in response to an external control signal.

VFDs are typically 92–98% efficient with 2–8% losses due to additional heat dissipation caused by the high-frequency electrical switching and the additional power required by the electronic components.

Advantages of using a VFD

In many applications, variable speed control can lead to substantial reductions in energy cost. The use of VFDs is particularly effective in fan and pump applications, where they can replace traditional power-regulation methods. Here, an exponential relationship exists between the machine speed (and output) and the energy used.

VFDs can enable energy savings and process efficiency due to improvements in the following areas:

- Speed control
- Flow control
- Pressure control
- Temperature control
- Tension control
- Torque control
- Monitoring quality
- Acceleration/deceleration control

In addition to energy savings, many a.c.-motor applications can benefit from the use of VFDs because they can also reduce operating costs by increasing system reliability and lowering maintenance requirements by reducing overall wear and tear

Evaluating VFD usefulness

The following actions can help determine whether installing a VFD makes sense for a particular application:

- Understand how the motor system meets the requirements of the process. Determine whether the demand is variable and to what extent it can be varied or reduced. Monitor the load profile to help establish when motor speed can be reduced and by how much
- Determine the load type, including whether its torque requirements vary and to what extent. Establish whether VFD control can be implemented on the system or if an alternative solution would be more appropriate or cost-effective
- Explore opportunities to maximize the existing system efficiency through low-cost measures, because there is little benefit in fitting a VFD to a system that already suffers from poor efficiency. Improve efficiency by other low-cost means along with the VFD
- Monitor the system's current energy consumption to estimate the energy-saving potential ■

Further reading

1. Prachyl, Stephen, Understanding Variable Frequency Drives, *Plant Engineering*, April 2011.
2. Shukla, D.K. and Chaware, D., Variable frequency drives: An Algorithm for Selecting VFDs for Centrifugal Pumps. *Chem. Eng.*, February 2010, pp. 38–43.
3. Ramey, Joseph, Variable Frequency Drives for Centrifugal Pumps, *Chem. Eng.*, November 2012, pp. 31–42.
4. GoHz.com, Variable Frequency Drive, www.variablefrequencydrive.org, accessed July 2015.

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Production of Polylactic Acid

By Intratec Solutions

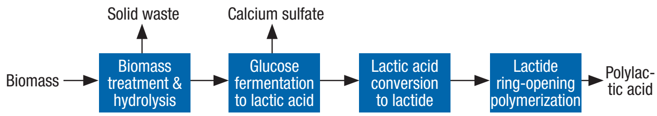

FIGURE 2. PLA is produced from lactide rings

Polylactic acid (PLA) is the biodegradable polymer of lactic acid, which is produced via fermentation processes. For the last five decades, PLA has been mainly used in biomedical applications. The development of economical production routes and a rising environmental awareness by the general public have pushed PLA uses to new markets, including consumer goods and packaging applications.

High-molecular-weight PLA can be produced through two main routes: an indirect route via a lactide intermediate, and a direct polymerization by polycondensation. The indirect route is the most common in industry, and is employed by two of the major PLA producers: NatureWorks LLC (Minnetonka, Minn.; www.natureworksllc.com) and Corbion-Purac (Amsterdam, the Netherlands; www.corbion.com).

In the indirect process, lactic acid is first oligomerized and depolymerized to produce lactide, a cyclic dimer of lactic acid. Then, through a ring-opening polymerization, lactide is converted to polylactic acid.

PLA production process

Figure 1 depicts a process for PLA production via a ring-opening polymerization process similar to that developed by NatureWorks. This process can be divided into two main areas: oligomerization and lactide formation; and lactide polymerization. In this process, the optical properties of the lactic acid feedstock are preserved in the polylactic acid.

Oligomerization and lactide formation. Lactic acid is fed to the oligomerization reactor, from which water vapor is removed, condensed and sent to a waste-treatment system. The resulting oligomer stream is mixed with catalyst and fed to the depolymerization reactor, which is a packed column operating under vacuum. Water, lactic acid and lactide are removed in the gaseous overhead stream. Most lactide and some impurities are condensed and sent to the drying column, where water is removed from the crude lactide. The remaining contaminants are removed in the purification column, leading to a 99.9% pure lactide product.

Lactide polymerization. The polymer-grade lactide undergoes a melt-phase polymerization. Molten lactide, a stabilizer and catalyst are fed to the polymerization reactor. The polymer melt is then pumped to a devolatizer operating under vacuum to remove unreacted lactide in the gaseous stream, which is condensed and recycled to the purification column. The devolatilized melt polymer is extruded, pelletized and dried, resulting in PLA as a final product.

Economic performance

An economic evaluation of a PLA plant was conducted, assuming a facility with a nominal capacity of 100,000 ton/yr of PLA constructed on the U.S. Gulf Coast. Storage capacity for the final product equal to 20 days of operation was assumed, but raw material storage was not included.

Estimated capital expenses (total fixed investment, working capital and initial expenses) to construct the plant are about $100 million, while the operating expenses are estimated at about $1,900/ton of PLA.

Global perspective

The recent decrease in oil prices has reduced the production costs for most fossil-fuel-based polymers, threatening the competitiveness of PLA projects. Efforts to reduce PLA production costs must be focused on acquisition of low-cost raw material. An alternative to allow access to less costly raw material would be the integration of PLA production with lactic acid production from a renewable feedstock, such as biomass (Figure 2; *Chem. Eng*. August 2015, p. 37).

In an attempt to reach new markets, some companies are researching methods for producing PLA with enhanced physical properties. These methods include the production of a polymer that consists of a mixture of poly(L-lactic acid) and poly(D-lactic acid). This polymer exhibits improved physical properties when compared to conventional PLA, produced exclusively from L-lactic acid feedstock. ■

Edited by Scott Jenkins

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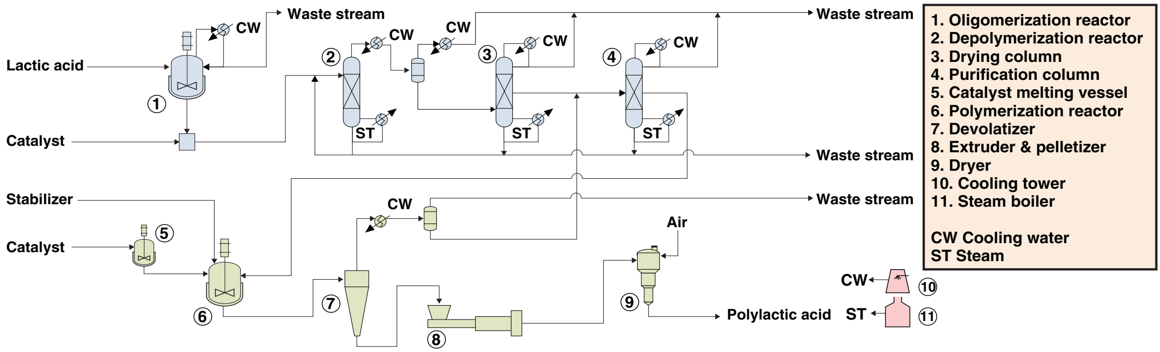


FIGURE 1. The PLA production process occurs via a ring-opening polymerization process similar to that of NatureWorks

Calculate NPSH with Confidence

Determining net positive suction head (NPSH) can be confusing, but with these guidelines, engineers can avoid the pitfalls of incorrect calculations

Asif Raza
Equipment Design Engineer

IN BRIEF

BASIC TERMINOLOGY

HOW NPSH IS CALCULATED

IMPLICATIONS OF INACCURATE NPSH

WAYS TO INCREASE NPSH

ENGINEERING BEST PRACTICES

Most engineers have likely heard the term NPSH (net positive suction head) at some point in their careers. Put simply, NPSH is the net pressure available at a pump's suction flange, expressed either as a height or a pressure value. Why is it so important? How is it calculated? What needs to be done to increase NPSH? What best practices are associated with NPSH? This article covers all these points in detail using practical examples. After reading this article, engineers will have a basic understanding of NPSH concepts and calculations, as well as the ability to solve simple NPSH problems.

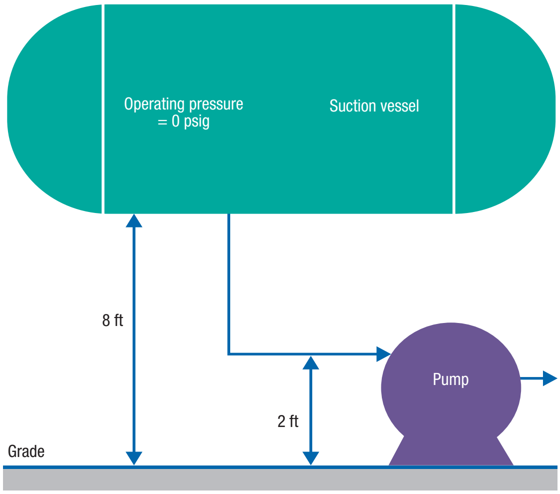


FIGURE 1. Drawing a system sketch is extremely helpful for gaining a better understanding of the system, and can be used to revise calculations during detailed design, especially if assumptions made during the basic design have changed

Basic terminology

The first step in understanding NPSH is to briefly define important basic terms that will help in clarifying the meaning of NPSH and guide engineers in its calculation.

Vapor pressure. By definition, vapor pressure is the pressure exerted by the vapor that is in contact with the fluid in consideration. This is the pressure exerted by vapor in thermodynamic equilibrium with its condensed phases at a given temperature. The vapor pressure of any liquid increases non-linearly with temperature, and at an elevated temperature, the vapor pressure equals the atmospheric pressure. When this happens, the fluid starts boiling. For example, consider a very common fluid — water. The vapor pressure of water at 10°C is 0.22 psia, while its vapor pressure at 100°C is 14.7 psia. Vapor pressure always increases with operating temperature and is most often expressed in psia.

Atmospheric pressure. The surrounding atmosphere exerts a constant pressure on everything. This pressure depends on the elevation relative to sea level, and starts decreasing with increasing elevation as the atmosphere starts getting thinner. It is nearly always expressed in psia.

Specific gravity. The ratio of the density of a fluid to the density of a referenced fluid is known as specific gravity. In most engineering calculations, the referenced fluid is water. Specific gravity is dimensionless.

Subcooled liquid. A liquid that exists below its normal saturation temperature is called a subcooled liquid. For example, water at atmospheric pressure boils at 100°C. Water at 50°C is a subcooled liquid.

Saturated liquid. A liquid that exists at the saturation temperature or boiling point that corresponds to a given operating pressure is said to be saturated. If any energy is added to the liquid, and the pressure is kept constant, some of the liquid will boil. A good example is a typical pressure cooker. A pressure cooker operates at elevated pressure so that the water can boil at an elevated temperature to properly cook food. If the pressure inside the cooker is decreased, the water would boil instantly and the pressure would be released in the form of steam. Another example is the liquid inside a distillation column that always exists at a saturated temperature.

NPSH available and required. The NPSH available (NPSHa) is a function of the system and should be calculated based on system design. The NPSH required (NPSHr) is a function of the pump itself and should be obtained from the pump manufacturer.

How NPSH is calculated

NPSH can be a difficult concept to grasp. To explain NPSH in simple terms, imagine a bonus received on a paycheck. However, the amount actually deposited into the bank account is much less than the bonus value, and it is later realized that the rest of the money has been deducted as taxes. What was deposited is the actual net bonus. It is a similar case for NPSH, which is the net pressure available for pump suction after all deductions, such as line losses and vapor pressure, are taken into account. In other words, it is the pressure available in excess over the vapor pressure to prevent the pumping fluid from boiling. The aim with NPSH is to provide an adequate amount of head exceeding the fluid's vapor pressure to prevent the fluid from boiling at the pump inlet. This excess head is defined as NPSH.

Calculating NPSH is relatively simple once the correct data have been collected. The sections below detail each piece of data that is required for NPSH calculations.

Site atmospheric pressure. NPSH calculations are impacted by the site's local conditions — specifically atmospheric pressure. This value is used in NPSH calculations, and the higher the atmospheric pressure, the better, with regard to NPSH. For instance, if a site is located in Mumbai, India, which is at sea level, the atmospheric pressure is exactly 14.7 psia. Hypothetically, if the site location is at a much higher elevation, say on Mount Everest, which is about 29,000 ft above sea level, the atmospheric pressure is just 4.4 psia. This puts into perspective the effect of site location on atmospheric pressure. So, it is crucial to do due diligence and find the correct atmospheric pressure for a site's location.

Suction piping layout. The physical layout of the suction piping is important in determining NPSH. This information must include the exact number of pipe fittings in order to properly determine the suction-piping pressure drop.

Vapor pressure of the pumping fluid. As explained earlier, vapor pressure is dependent on the operating temperature. Vapor pressure for pure substances can be found in literature, such as Perry's Chemical Engineers' Handbook [*1*]. There are also many resources available online, including Ref. 2, which has a comprehensive list of pure substances in its

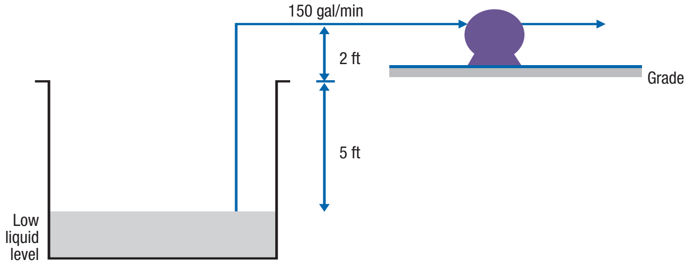


FIGURE 2. This system sketch shows a pump configuration where there is negative suction lift, meaning that the pump is located higher than the source suction vessel. The low liquid level should be considered in NPSH evaluations for a more conservative approach

database. To determine the vapor pressure, the operating temperature must be provided.

Suction vessel elevation and operating pressure. It has already been stated that the overall site elevation affects the NPSH of a given pump layout. The elevation of the suction vessel (the tank or vessel from which the liquid is being pumped) itself is also important. Additionally, the operating pressure of the suction vessel must be known. A system sketch can be helpful in visualizing the pumping system layout and the suction elevation. Figures 1 and 2 show some examples of typical pumping system sketches.

Pump dimensional drawings. If available during early stages in design, a sketch of the specific pump model can be very helpful.

Now that the basic terms and required data have been outlined, actual NPSH calculation can begin. Consider this example comparing water at two temperatures. Water is being pumped from a vessel at atmospheric pressure at a rate of 200 gal/min. The suction line is 3-in. carbon steel and the site atmospheric pressure is 13 psia. How will the NPSH be impacted by temperature if the water is at 95°C? What if the water temperature is 30°C? Assume this is a new design and the tank elevation and piping layout are fixed. The following are the required steps for solving this problem:

1. Contact the pump vendor and get a pump datasheet based on the process data. Vendors will often provide a value for the required NPSH of a particular pump model. For this example, assume that the pump vendor lists NPSHr as 6 ft. Figure 3 shows the relationship between NPSHr and flowrate from a typical pump curve. Pump

FIGURE 3. Vendor-provided pump curves provide engineers a wealth of information, including the NPSH required for a specific pump model over a range of flowrates

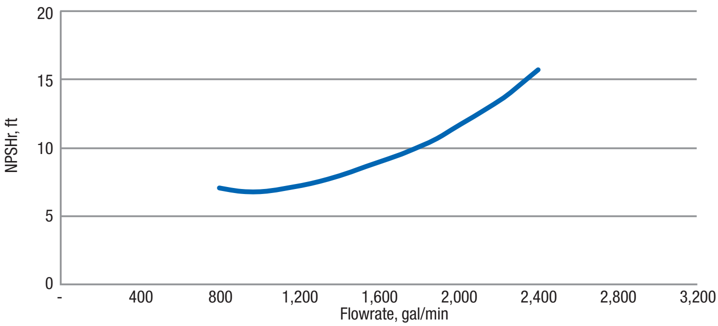


TABLE 1. NPSH CALCULATIONS FOR WATER AT 95 AND 30°C

	Water at 95°C				Water at 30°C			
	Input data		Calculated values		Input data		Calculated values	
Atmospheric pressure at project site	13	psia			13	psia		
Liquid specific gravity	1				1			
Pressure above the liquid (operating pressure)	0	psig	(13+0) × 2.31/1 = 30.03	ft	0	psig	(13+0) × 2.31/1= 30.03	ft
Static head (distance from the low-low liquid level in vessel to the pump suction flange)	6	ft	6	ft	6	ft	6	ft
Suction friction losses (calculated based on suction-piping isometrics and pump rated flowrate)	0.5	psid	0.5 × 2.31/1 = 1.16	ft	0.5	psid	0.5 × 2.31/1 = 1.16	ft
Pressure at pump suction (pressure head above liquid + static head – piping suction loss)		ft	(30.03 + 6) - 1.16 = 34.87	ft		ft	(30.03 + 6) – 1.16 = 34.87	ft
Vapor pressure at operating temperature	12.26	psia	12.26 × 2.31 / 1 = 28.32	ft	0.615	psia	0.615 × 2.31 / 1 = 1.42	ft
NPSH available (pressure head at pump suction – vapor pressure)			34.87 – 28.32 = 6.55	ft			34.87 – 1.42 = 33.45	ft
NPSH (required) based on pump vendor's datasheet			6	ft			6	ft
Satisfactory margin of 3 ft over NPSH required			6 + 3 = 9	ft			6 + 3 = 9	ft
Compare NPSH available versus NPSH required			Margin of 3 ft or more available?	No			Margin of 3 ft or more available?	Yes

TABLE 2. NPSH CALCULATIONS FOR WATER AT 30°C WITH NEGATIVE SUCTION LIFT

	Water at 30°C			
	Input data		Calculated values	
Atmospheric pressure at project site	13	psia		
Liquid specific gravity	1			
Pressure above the liquid (operating pressure)	0	psig	(13 + 0) × 2.31 / 1 = 30.03	ft
Negative static head (distance from the low-low liquid level to the pump suction flange)	5 + 2 = 7	ft	5 + 2 = 7	ft
Suction friction losses (calculated based on suction piping isometrics and pump rated flowrate)	1.5	psid	1.5 × 2.31 / 1 = 3.46	ft
Pressure at pump suction (pressure head above liquid – negative static head – piping suction loss)		ft	(30.03 – 7) – 3.46 = 19.61	ft
Vapor pressure at operating temperature	0.615	psia	0.615 × 2.31 / 1 = 1.42	ft
NPSH available (pressure head at pump suction – vapor pressure)			19.61 – 1.42 = 18.19	ft
NPSH (required) based on pump vendor's datasheet			6	ft
Satisfactory margin of 3 ft over NPSH required			6 + 3 = 9	ft
Compare NPSH available versus NPSH required	Yes or no?		Margin of 3 ft or more available?	Yes

curves illustrate many useful parameters, such as the relationship between flowrate and head, power, NPSH and efficiency. Engineers should read all of the parameters with respect to their pump's normal and rated flow, and always base calculations on their pump's rated flowrate. Notice that the NPSHr curve is slightly bowl-shaped, and that NPSHr increases with flow. Make sure that the entire operating range is taken into consideration while reading a pump curve.

2. Calculate the pressure drop in the suction line as accurately as possible, considering the layout and all fittings.
3. Obtain the pump dimensional drawing from the vendor.
4. Get the source (suction) vessel drawing to see the orientation of the nozzles and the elevation.
5. Determine the respective vapor pressure of water at each considered temperature. In this example, the vapor pressure of water at 95°C is 12.26 psia and the vapor pressure of water at 30°C is 0.615 psia.
6. Determine the site atmospheric pressure. For this example, it is 13 psia.

Table 1 shows the calculations required to determine the NPSH available for water at each temperature with the inputs defined in the preceding sections. Table 2 illustrates the NPSH calculations at 30°C in a negative suction-lift scenario. Based on good engineering practice, an assumed design margin (3 ft) is applied, meaning that the NPSHa should be at least 3 ft greater than the NPSHr.

Based on the given inputs, the NPSH at 95°C is 6.55 ft, but the NPSH at 30°C is 33.45 ft. The static head and piping friction loss are the same in both cases; the only difference is the vapor pressure, which is much higher for the higher temperature case. This illustrates why using an accurate vapor pressure is crucial, as it has a significant effect on the calculations.

Very special care should be taken when dealing with boiling liquids or saturated liquids, such as the liquids from distillation columns or from reflux condensers. In these situations, the operating pressure does not help, and no credit can be taken, since the vapor pressure will be equal to the operating pressures. In these cases, high static head and low friction losses in the suction piping are the only additional sources of gain.

Implications of inaccurate NPSH

As explained earlier, if excess head is not provided over the vapor pressure, the fluid starts boiling at the pump inlet. Instead of a steady stream of liquid entering the pump inlet, two-phase flow is introduced at the eye of the pump impeller. The pump impeller moves the fluid to a higher pressure and the void of gas present within the boiling fluid starts collapsing on the impeller with force, producing a shockwave and, typically, a loud thudding sound. These collapsing voids cause cyclic stress through repeated implosion, which starts damaging the impeller. The thudding noises are due to vapor bubbles collapsing on the impeller. Some of these problems occur due to a variety of reasons: NPSH has not been not calculated correctly; the pumps have been relocated in different service (perhaps to systems with different layout or elevation); or the process conditions changed due to suction piping modifications and the designer did not reassess the NPSH available.

The problems are more severe in larger pumps, since increased amounts of bubbles are formed and implode on the high-pressure side of the impeller. When this happens, the capacity of the pump is greatly reduced and the impeller sustains damage. Additionally, the radial and thrust bearings can be damaged because the energy absorbed by the pump is not effectively transferred to the fluid. Sometimes the problem may be so severe, especially in high-speed pumps, that the shaft is subjected to high levels

FIGURE 4. Flow inducers can be installed inside the pump casing to decrease the NPSH required. Flow inducers are available in many sizes and metallurgical options

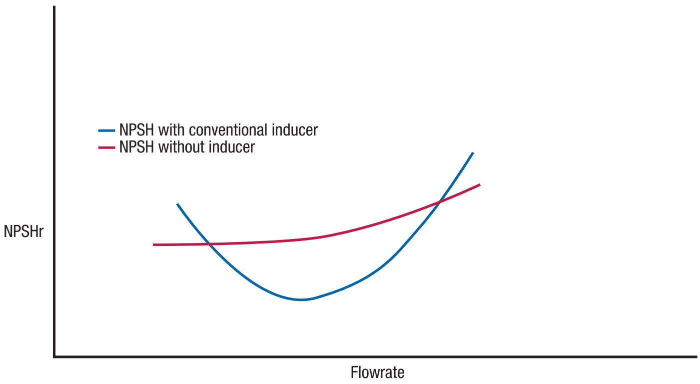


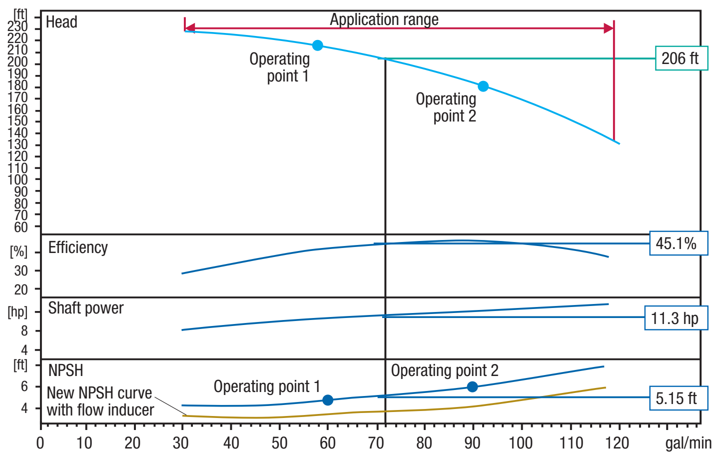
FIGURE 5. Notice how the NPSH requirement of the pump is decreased with the addition of a flow inducer. It is worth mentioning here that the NPSH requirement of the pump increases sharply with increasing flow. It is very important to operate the pump within the specified range where the NPSH is within acceptable limits

of stress and becomes misaligned.

Engineers should be very careful and complete the proper analyses before selecting a pump and finalizing the system design. Once the system design is complete and constructed, very little can be done to alter the system, and the only option may be to change the pump or re-configure the suction piping, both resulting in additional costs and downtime.

This phenomenon occurred in a polyisobutane plant where two reactor-bottoms pumps were installed. The more recently installed pump would cavitate because proper NPSH calculations were not carried out for the new pump's piping layout. The new pump-suction piping length was routed with many elbows, and the pressure drop was high, leading to a lower NPSH available for the pump, which was not considered when the pump was installed. The suction piping had to be re-routed, which effectively increased the available NPSH. However, all of these modifications were completed during plant shutdown, resulting in considerable production losses. Diligently collecting the proper data for NPSH calculations can make a significant impact on plant operations.

FIGURE 6. The pump curve shows not only the NPSH, but also the shaft power, efficiency and head, across the pump's entire operating range



Ways to increase NPSH

Frequently during the early design stage of a project, the NPSH calculations are based on a preliminary piping layout. This is when engineers may find that they are dealing with low NPSH. Steps that can be taken to increase NPSH are as follows:

- Contact the piping-layout designer to see whether they can increase the elevation of the suction vessel
- Check whether increasing the size of the suction piping reduces the pressure drop and increases the NPSH available
- Consult with the vendor to see if a bigger impeller is available. Pumps with larger impellers have better NPSH values. However, the penalty for bigger impellers is a higher power consumption
- Check with the vendor for a slower-speed motor. Pump manufacturers may suggest a slow-speed motor to reduce NPSH-related problems. With a slower motor, high static head is available at the suction and improves NPSH
- Determine whether the pump can be physically lowered inside a pit or sump to increase the static head
- If the process allows, lower the temperature of the pumping process to decrease vapor pressure. A practical example is a molten-sulfur pump in a batch process that cavitated when the temperature of the reactor was high; the high temperature led to high vapor pressure and decreased NPSH availability. The plant personnel analyzed the problem, and instead of changing the pump, they decided to install a cooling-water jacket on the suction piping. The slight cooling of the fluid was enough to adequately run the pump
- Check with the pump vendor to determine whether a flow inducer (Figure 4) is available for your pump. If available, ask for a NPSH curve that also shows the NPSH with a flow inducer installed (Figure 5) and check the NPSH requirement. A flow inducer is a small impeller that is installed inside the pump casing just before the pump's main impeller. Simply, it can be defined as a small booster pump ahead of the main pump that increases the static pressure of the pumping fluid at the pump suction, reducing the NPSHr. The NPSH requirement of the flow inducer is very low

Now that the implications of improper NPSH calculations and the benefits of flow inducers are understood, consider another example problem. There is an existing cryogenic pump in liquid argon service that is designed for 60 gal/min at 210 ft of head. The plant decides to relocate the pump to a location where 90 gal/min at 180 ft of head is required. Here, it must be determined whether the pump can be used in this newly specified service, and any potential modifications required to achieve this must also be evaluated. Figure 6 shows the pump curve for the pump in question. The steps for solving this problem are as follows:

1. Check the pump curve to make sure that the pump can achieve the desired head at the requested flowrate. Draw a straight line from 90 gal/min on the capacity-head chart and then read the corresponding head value. It is seen that it is possible to achieve 90 gal/min at 180 ft of head.
2. Calculate the NPSH available from the sample calculations discussed earlier. For this instance, assume the available NPSH is 6 ft.
3. Read the NPSH curve in Figure 6 to check the NPSHr at 90 gal/min. It is 6 ft, and the available NPSH is also 6 ft. In this scenario, there is no room for the minimum design margin of 2 ft, hence the NPSH available must somehow be increased. Based on the previously provided guidelines on what can be done to increase NPSH, consider whether using a flow inducer may work.
4. Contact the vendor and ask whether there is a flow inducer available for this pump. Assume that the vendor confirms that there is indeed a flow inducer available, and provides a pump curve with the flow inducer. It is seen in Figure 6, that with the flow inducer, the NPSH requirement at 90 gal/min drops to 4 ft. Now, there is a design margin of 2 ft available, satisfying the design requirements. Therefore, with the installation of a flow inducer, this design change can be implemented.
5. The final step is to confirm with the vendor regarding the new horsepower requirement at the higher flowrate of 90 gal/min at 180 ft of head. Use this information to make sure the existing motor is adequate or if it will need replacement. Working with an electrical engineer may be required to make the correct decision regarding pump motor replacement.

Engineering best practices

While calculating NPSH, follow these guidelines to ensure a quality system design:

1. Calculate NPSH using the low liquid level in the suction tank. This is a conservative approach, and ensures that a pump will work, even at low liquid levels. This also ensures that the liquid inventory in the storage tank is utilized to the fullest.
2. To avoid excessive pressure drop, design the suction piping with the minimum number of elbows and fittings. Also, suction piping should be short as possible. Target a maximum pressure drop of 0.5 psi.
3. If the pump is connected with a reducer, use an eccentric reducer with the flat side up. This arrangement ensures that the entrained vapor bubbles will migrate back to the source instead of remaining near the pump suction. Be sure to follow any specific installation procedure that is recommended by the pump vendor.
4. If the line is insulated for personnel protection, consider removing the insulation and installing a metal barrier for personnel protection. Removing the insulation will help the fluid to cool down, lower the vapor pressure and achieve a higher value for NPSH available.
5. A design margin of at least 2–3 ft should be allowed between the NPSH required and the NPSH available. The NPSH available should always be greater than the NPSH required.

Through close coordination with pump vendors and the development of a solid understanding of the basic terms, including vapor pressure, saturation, pressure drop and rated flow, engineers will be on the right track to calculate NPSH and properly design pumping systems that meet customer or plant requirements. ■

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References

1. Green, D.W., Perry, R.H., "Perry's Chemical Engineers' Handbook," 8th Ed., McGraw-Hill Professional, New York, N.Y., 2007.
2. Ohe, Shuzo, Vapor Pressure Calculation, www.e-data.jp/vpcal1/e/, 2010.

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Part 2

The Benefits of Seal-less Pumps for Full Product Containment

In cases where full containment of dangerous and hazardous chemicals is necessary, seal-less pumps can provide many safety and operational benefits

Chrishelle Rogers and **Nicholas Ortega**
PSG, a Dover company

IN BRIEF

SEALING CHALLENGES

SEAL-LESS PUMP TECHNOLOGIES

SEAL-LESS PUMPS IN OPERATION

FIGURE 1. Almost all chemical transfer applications employ some sort of pump, and some types of pumps can unfortunately introduce the potential for leaks. Leaks of dangerous chemicals can be catastrophic, but for applications where full product containment is required, seal-less pumps can provide protection

To the average person, many of the raw materials that are commonly used in the chemical process industries (CPI) can resemble either a steaming bowl of alphabet soup — KOH, NaOH, HCl and HF, for example — or a bad Scrabble rack — toluene, hexene and xylene, for instance. However, those who make a living manufacturing chemical-based products, such as caustics, acids, solvents and polymers, know that while high-value chemicals are pivotal to production processes, they can also be extremely dangerous and potentially harmful to site personnel and the environment if not handled properly. If a leak does occur, the safety of site personnel and surrounding communities can be put at risk with the potential for injury or loss of life.

This is a constant concern for manufacturers, as hazardous chemical compounds are used in a large number of industries and products, including adhesives, biofuels, petroleum additives, polyurethane foam, coatings and more. In addition to being widely used and potentially dangerous or hazardous if mishandled, many chemical compounds are also extremely expensive. If a leak were to occur during the handling or transfer of these products, large costs would be incurred by the operator due not only to the loss of raw materials, but also for cleanup and potential environmental remediation. All of these factors combine to make the full containment of dangerous chemicals a primary concern for facility operators.

Crucial pieces of equipment that are utilized during the manufacture and handling of dangerous chemicals are the pumps that either introduce raw materials into the production process or transfer end products for packaging, storage or shipping to end users (Figure 1). Mechanically sealed pumps are commonly used for these transfer activities. This article illustrates how another pump type — seal-less pumps — can be employed when full containment of dangerous and valuable chemicals is an absolute must.

The Hydraulic Institute (Parsippany N.J.; www.pumps.org) defines a seal-less pump as "one in which the rotor is contained in a sealed, pressurized vessel that contains the process fluid." This means that all sealing between the process fluid and the atmosphere is done through static sealing technologies like gaskets, O-rings and so on. No mechanical seals or packing are relied upon to seal the process fluid from the atmosphere. These qualities can often make seal-less pumps a more effective option for product containment than their mechanically sealed counterparts.

FIGURE 2. A shortcoming of mechanically sealed pumps in the CPI are the catastrophic failures that can occur when the seals fail, potentially causing dangerous leaks

Sealing challenges

When handling dangerous chemicals, there are four main areas of concern for manufacturers, outlined in the sections below.

Safety. Ensuring that site personnel, surrounding communities and the environment are not harmed is of utmost concern to manufacturers, especially in processes where hazardous chemicals are involved.

Product containment. When dangerous or hazardous products are fully contained and not allowed to leak, valuable raw materials and products are not lost to the environment, improving safety overall.

Maintenance. Mechanical shaft-seal failures are the primary cause of pump downtime. Excessive maintenance costs generally are accumulated in two ways: the need to constantly repair, rebuild or replace underperforming pumps or components; and in the downtime that brings operations to a grinding halt.

Operating costs. There are some operating costs that are intrinsic to mechanically sealed pumps. For instance, seal-flush water is a source of costs that is often overlooked in pumping operations. The impact of the seal water on the process operations, as well as the cost of the flush water, must be taken into account.

The most common pump technologies that are used in the manufacture and handling of dangerous chemicals include diaphragm, sliding-vane, lobe, progressive-cavity, centrifugal and gear. All of the traditional pump technologies have one thing in common: they rely on various types of seals to prevent shaft leakage. The two most common types of seals — packing rings and mechanical seals — are used in many applications that handle hazardous chemicals, but they both have their own potential shortcomings.

Packing-ring sealing methods utilize braided packing materials that include a set of formed rings that are wrapped around the pump shaft and held in place by an adjustable gland that has been designed to control shaft leakage. A small amount of leakage is required for lubrication and cooling. Packing has been widely used in a variety of industries (such as in resin, paint and coatings), but should not be generally considered a best practice for handling hazardous chemicals.

Mechanical seals come in two general variations: single and double. Single mechanical seals can usually adequately address the problem of fluid leakage, but when used with liquids of higher viscosity, the product drag can distort the seal or cause it to break away from the shaft completely. Single mechanical seals also are incapable of containing potentially hazardous vapors. Double mechanical seals can prevent the escape of vapors and are more reliable when handling viscous liquids, but they can be prohibitively expensive to acquire, repair, clean and maintain.

While any of the various types of seals can perform admirably for long periods of time, they will eventually require maintenance or may need to be replaced before major shaft leakage occurs. Replacing the seals, not only after they fail, but also as a form of preventative maintenance, is costly.

The cost of a leak to a manufacturer includes the loss of valuable raw materials or finished products, downtime in production, and the costs and potential penalties associated with chemical cleanup efforts. Figures 2 and 3 illustrate some situations where pump leaks caused extensive, catastrophic

FIGURE 3. When leaks occur, valuable raw materials and end products are irretrievably lost, while the safety of plant personnel and the environment is put at risk. Damage is also done to the operation in the form of expensive costs for cleanup, downtime, parts replacement or the purchase of a brand-new pump

FIGURE 4. Seal-less sliding-vane pumps are designed to maximize bearing life and minimize metal-to-metal contact

damage. Leaks of hazardous materials that reach the outside environment can be subject to fines and remediation costs from the U.S. Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov), as well as other local and state regulatory agencies. Additionally, other countries have their own sets of regulations, which can often be more stringent than those in the U.S. Spilled hazardous materials also pose safety risks for site personnel and cleanup crews, which raises liability issues.

Most seal-less pumps, on the other hand, have built-in safeguards that enable the containment of the liquid in the event of a catastrophic pump failure. Depending on the level of protection required for the application, further precautions can be taken by utilizing double-wall containment shells and leak-detection technology that triggers automatic shutdown of the pump.

FIGURE 5. Some seal-less internal-gear pumps feature only one fluid chamber, which not only enhances product containment, but also eliminates product entrapment, especially when transferring high-viscosity liquids

Seal-less pump technologies

While sealed pumps can perform sufficiently in the manufacture, transfer and handling of dangerous chemicals and other hazardous materials, the shortcomings that are inherent in their sealed design can make them insufficient for some jobs. In these cases, manufacturers should seek out alternative pumping technologies that can help eliminate some of the major concerns associated with achieving full containment, including seal-less sliding-vane, internal-gear and eccentric-disc pumps.

Sliding-vane pumps. Seal-less sliding-vane pumps (Figure 4) generally feature a magnetic coupling consisting of samarium-cobalt magnets and a specially designed bearing-and-head configuration that allows a small quantity of the pumpage to circulate through the containment can and onto the bearing surfaces. This positive flow of fluid minimizes temperature rise during operation, which helps maximize bearing life. Replaceable 316 stainless-steel end discs allow easy rebuilding of the pumping chamber to like-new condition without having to remove the pump from the piping. Additionally, the pumps' carbon-graphite sleeve bearings help ensure no metal-to-metal contact during operation. Operationally, seal-less sliding vane pumps offer the same advantages as their sealed counterparts: volumetric consistency, self-priming and limited dry-run capability, drain plugs that facilitate draining and easy replacement of worn vanes.

Internal-gear pumps. Recent advancements in internal-gear-pump (Figure 5) design and operation have allowed for the development of models that feature only one fluid chamber. This method of construction removes the adapter plate that is a staple of traditional two-chamber magnetically coupled internal-gear pumps, which eliminates product entrapment concerns, especially when transferring high-viscosity liquids. One-chamber operation is achieved through a between-the-bearings design that places the magnets directly on the pump rotor, resulting in a simpler flow path and full leak-free product containment. Some seal-less internal-gear pump models are also constructed of as few as seven parts, which helps contribute to an estimated 50% reduction in maintenance costs when compared to sealed pumps. There are also seal-less internal gear pump models that are interchangeable with nearly all competitive sealed or packed-gear pump brands, enabling drop-in replacement.

Eccentric-disc pumps. Seal-less eccentric-disc pumps (Figure 6) feature no mechanical seals, packing, couplings, or even magnets — the shaft is instead sealed by a double stainless-steel bellows. Operationally, seal-less eccentric-disc pumps can still offer self-priming, dry-run and low-shear operation, very high suction and discharge pressures, the ability to pump both low- and high-viscosity liquids and clean-in-place and sanitize-in-place (CIP/SIP) capability. The pump's eccentric-disc operating principle features an eccentric shaft that rotates, allowing the disc to form chambers within the cylinder. When the discharge pressure exerts itself against the eccentric disc, slip is prevented, which gives eccentric disc pumps the ability to reliably self-prime and line strip. This operating principle also allows for air to be pumped, meaning that seal-less eccentric-disc pumps can achieve product-recovery rates of 90% or more on the suction side and 60 to 80% on the discharge side of transfer lines. This enhanced product-recovery capability can result in cost savings due to the retrieval of still usable raw materials and saleable end products.

Seal-less pumps in operation

Provided that the proper precautions, which are the same for traditional sealed pumps, concerning safety, pump mounting, coupling alignment, flange loading and startup procedures, are taken, these varying types of seal-less pump technologies satisfy all operating demands with regard to overcoming the major challenges of handling dangerous chemicals or other hazardous materials: optimized safety; full product containment; reduced maintenance; and streamlined operating costs.

The ultimate result is that positive-displacement seal-less pump technologies can reliably provide safety and full containment when used in some dangerous industrial chemical-handling applications, including those that involve the following: adhesives, biofuels, sodium hydroxide, lubricant oils and grease, paints and coatings, petroleum additives, polyurethane, molten sulfur, resins, soaps and detergents, vegetable fat and hot oil.

However, there are also a few critical applications that are not ideal for reliable operation of seal-less pumps of which users should be aware. These are applications involving fluids with moderate to high percentages of solids, applications involving crystallizing or solidifying fluids where reliable pump jacketing is not used and applications involving extremely viscous fluids above approximately 55,000 cSt. In all three instances, the concern is the potential blockage of the magnetic-coupling cooling path during operation.

Sealed pumps have been performing sufficiently in chemical-manufacturing operations for many years. However, operators who are looking for a leak-preventing alternative should look to upgrade their facilities with seal-less pumps. These types of pumps will reduce leakage events and improve containment of dangerous or hazardous materials. Maintenance costs can also be lowered to such a level that the lifetime cost to operate the seal-less pump may be half that of a sealed model in some cases. Furthermore, the use of seal-less pumps can increase users' peace of mind, which comes with the knowledge that not only is personal and environmental safety being optimized, but that the bottom line is receiving a boost, as well. ■

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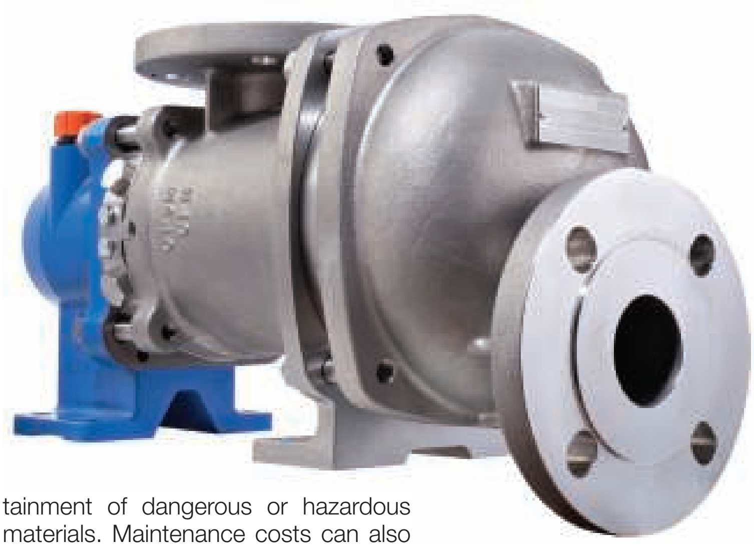

FIGURE 6. Seal-less eccentric-disc pumps feature no seals, packing, couplings or magnets, enabling full product containment

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Treating Wastewater for Industrial Reuse

Secondary treated wastewater from municipal plants can be a water resource for industry. Important water characteristics and treatment options are discussed

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IN BRIEF

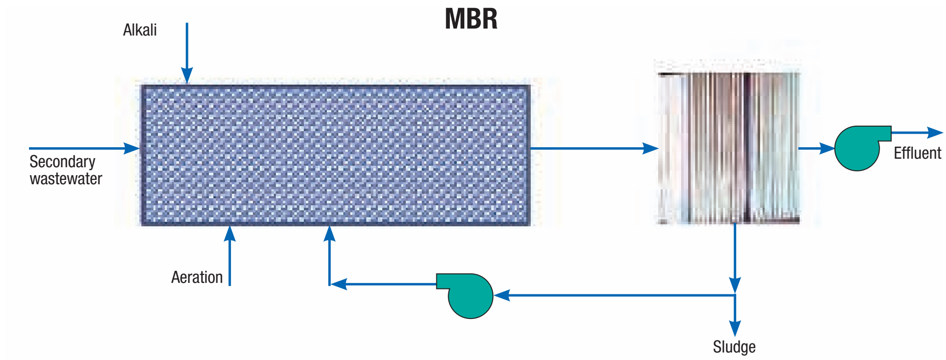

FIGURE 1. A typical external side-stream membrane bioreactor (MBR) is depicted here

Water is a precious resource, and water quality and water pollution are important issues. Many companies and industries are trying to be "green" by reducing well-water and river-water consumption. In an effort to be more environmentally responsible, to alleviate water scarcity issues, and to be compliant with federal, state and local regulations, secondary treated wastewater from municipal water plants is currently being used in various industries to replace makeup water taken from wells, lakes and rivers. Municipal wastewater-treatment plants are frequently located near industrial water users, such as power plants, which helps to create this opportunity.

California and Florida are the two largest users of the reclaimed water in the U.S. In 1995, the U.S. Geological Survey (USGS) study revealed that 95% of water reuse in the U.S. occurred in just four states, including Arizona, California, Florida and Texas. Now, this value is less than 90% due to increased water reuse in several other states, including Nevada, Colorado, New Mexico, Virginia, Washington, Oregon, New Jersey, Pennsylvania and New York. In response to drought, population growth and new regulations, future water reuse in California is estimated to reach 2 million acre-foot per year (ac-ft/yr) by 2020 and 3 million ac-ft/yr by 2030. California presently reuses 650,000 ac-ft/yr.

This article discusses the characteristics of secondary treated wastewater, and options for treating that water so that it is suitable for use in industrial demineralization systems and cooling towers. Relevant technologies are described and evaluated, giving advantages and disadvantages. An example and a case study are presented. Specifically, the technologies considered in this article are the membrane bioreactor (MBR), moving bed biofilm reactor (MBBR), and biological aerated filter (BAF). Considerations are included for sending secondary treated water directly to demineralization systems and cooling towers, with only chemical additives as a pre-treatment step.

The choice of the biological treatment system depends on the specific application, technical requirements, and consideration of the capital and operating expenditures (Capex and Opex). The performance and availability of the system is critical, when used for industrial plants.

Characteristics of secondary treated wastewater

Water from municipal sources, such as residential wastewater, is sent to municipal wastewater-treatment plants, which are also called publicly owned treatment works (POTWs), for primary and secondary treatment. Primary treatment includes coarse debris screed, sand and grit removal and clarification.

Secondary treatment includes attached-growth or suspended-growth biological treatment (using aeration), secondary clarification and disinfection. The primary and secondary treatments at municipal water-treatment plants remove most of the biochemical oxygen demand (BOD) and suspended solids. Typical secondary-treated-wastewater characteristics are pH 6 to 9, total suspended solids (TSS) of 35 mg/L, ammonia-N content of 35 mg/L, BOD of 25 mg/L, and chemical oxygen demand (COD) of 125 mg/L. As an example of industrial use, the typical requirements for power-plant cooling-tower makeup are pH 6.8 to 7.2 or 7.8 to 8.4, TSS 5 to 30 mg/L, ammonia-N 1–5 mg/L, and total phosphorus as phosphorus (TP–P) less than 1 to 5 mg/L depending on the cooling-tower cycles of concentration. The following is true for cooling tower makeup:

- Ammonia increases corrosion rates of copper alloys; is a nutrient for microbes; and irreversibly reacts with chlorine
- High suspended solids cause fouling
- Phosphate (PO_4^{3-}) causes scale formation with calcium; and is a nutrient for microbes, causing biofouling

The tertiary treatment reduces the residual organic, ammonia, suspended solids and toxic chemical levels.

Guidelines for treatment levels

The treatment level to be obtained is set by the 2012 U.S. Environmental Protection Agency (EPA) Guidelines for Water Reuse, state regulations, and cooling tower and demineralization makeup requirements. Table 1 lists the typical constituents of secondary treated water, and the possible tertiary treatment options. Along with the capacity, constituents, and constituent-removal requirements, the temperature and pH are very important in deciding the type of technology and the size of equipment.

The sludge generated in the tertiary treatment is typically recycled to the same POTW that provided the secondary treated wastewater.

The 2012 EPA Guidelines for Water Reuse present industrial water reuse guidelines in various U.S. states. Water quality requirements for industrial reuse are lower than the unrestricted urban-use criteria because of reduced contact potential with individuals. Bacteriological quality varies from 2.2 total coliform/100 mL to 200 fecal coliform or *E. coli*/100 mL. Carbonaceous BOD monthly averages are 15 to 30 mg/L and TSS limits are 5 to 45 mg/L. Nutrient removal is an important step for industrial reuse, but it is not directly addressed in the EPA guidelines. To control these constituents, several biological wastewater-treatment options are discussed in this article, including MBR, MBBR and BAF.

TABLE 1. WATER TREATMENT PROCESSES FOR TREATING SECONDARY TREATED WATER

Constituents	Treatment
Ammonia	Biological treatment: Membrane bioreactors (MBR) Moving bed biofilm reactors (MBBR) Biological aerated filters (BAF) Trickling filters (TF)
Oil and grease	
BOD	
COD	
TOC	
TP-P	
TSS	Clarification, multimedia filtration, and microfiltration/ultrafiltration
Turbidity	
Al	Lime softening and pH adjustment
Fe, Mn	Aeration/chlorination, greensand filtration, lime softening, pH adjustment
Ca, Mg	Lime softening
SiO_2	Lime softening, supplemental magnesium

MBRs, MBBRs and BAFs

Membrane bioreactor (MBR). A common external side-stream membrane bioreactor is shown in Figure 1. The MBR system is a combination of an activated sludge bioreactor (suspended growth) and low-pressure membrane filtration. Secondary treated wastewater from a POTW enters a grid, is screened, and is then mixed with chemicals and activated sludge in an aerated bioreactor, followed by low-pressure acti-

TABLE 2. ADVANTAGES AND DISADVANTAGES OF THE MEMBRANE BIOREACTOR

MBR Advantages	MBR Disadvantages
1. Eliminates solid / liquid separation and tertiary filtration; replaces the need for clarification, multi-media filtration and ultrafiltration 2. Great effluent water quality 3. Pretreatment for nanofiltration and reverse osmosis 4. Handles influent variability 5. Small footprint 6. Automation is relatively simple and reliable 7. Low hydraulic retention times	1. Additional membrane cleaning is required 2. Membrane maintenance 3. Fouling 4. High electric power requirement (air scouring) 5. Fairly new for tertiary application 6. High Opex 7. High Capex 8. Waste sludge can have a low settling rate

TABLE 3. ADVANTAGES AND DISADVANTAGES OF MOVING BED BIOFILM REACTORS (MBBR)

MBBR Advantages	MBBR Disadvantages
1. Great effluent quality 2. Handles influent fluctuations 3. Small footprint 4. Lower power consumption 5. Increased biomass IFAS (integrated fixed-film activated sludge) mode 6. Stable under large load variations	1. Requires clarification and multimedia filtration 2. Ultrafiltration is needed for demineralization system 3. Media maintenance 4. High chemical costs 5. Has coarse bubble diffusers that have very poor oxygen-transfer efficiencies

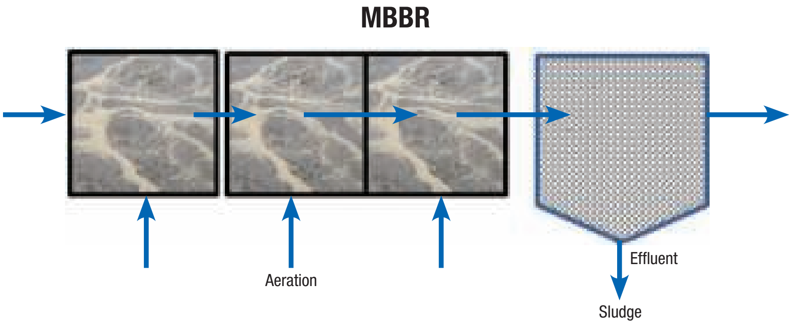

FIGURE 2. **This schematic shows a moving bed biofilm reactor (MBBR) with water flowing from left to right through media with aeration**

vated membranes for solid and liquid separation (microfiltration).

Typical mixed-liquor suspended-solids concentrations in MBR systems are 10,000–12,000 mg/L. The two types of membranes available for use in MBR include hollow-fiber and flat-sheet membranes. The MBR technology replaces clarification, disk filtration or ultrafiltration required in industrial plants. Effluent is sent to the service water tank, or plant water system, and from there to the demineralization systems and cooling water system. With an MBR, the effluent can attain NH_3-N concentrations less than 1 mg/L, BOD of less than 5 mg/L, and COD of less than 50 mg/L.

Table 2 lists the advantages and disadvantages of the MBR. Effluent water quality and ability to handle influent variability are the major reasons that many MBRs have been installed over the past 50 years.

Moving bed biofilm reactor (MBBR). A schematic of an MBBR is shown in Figure 2. Secondary treated water flows from left to right, through biofilm carrier elements or media in an aerated bioreactor. The biofilm is attached to the media. Typical carrier elements look like pretzels with inner and outer grooves and ridges: but the quantity, shapes and sizes depend on the specific application, based on water temperature, pH, capacity, constituents and required effluent quality.

Activated sludge and microorganisms that are free-floating attach to the media and form biofilm. The sludge that is free-floating passes with the wastewater to a clarifier. A portion of the sludge is removed and sent back to the POTW.

The integrated fixed-film activated sludge (IFAS) variation of the MBBR process takes its name from the integration biofilm media technology inside the conventional activated sludge, where some of the sludge is recycled back to the MBBR. The IFAS/MBBR requires return activated sludge (RAS) pumps and piping. The MBBR produces an effluent with NH_3-N levels of less than 1 to 3 mg/L, NO_3-N less than 1 mg/L and total nitrogen (TN) less than 3 mg/L. Table 3 lists the advantages and disadvantages of the MBBR.

An example of a power-plant water balance using an MBBR/clarifier system is shown in Figure 3. The 1,000-MW combined cycle plant has three gas turbines with heat recovery steam generators (HRSG), and one steam turbine, one demineralization system and one cooling system.

Biological aerated filter (BAF). The BAF shown in Figure 4 was introduced in the early 1980s. This system has lower operating and maintenance costs and a smaller footprint than the MBR and MMBR. The BAF

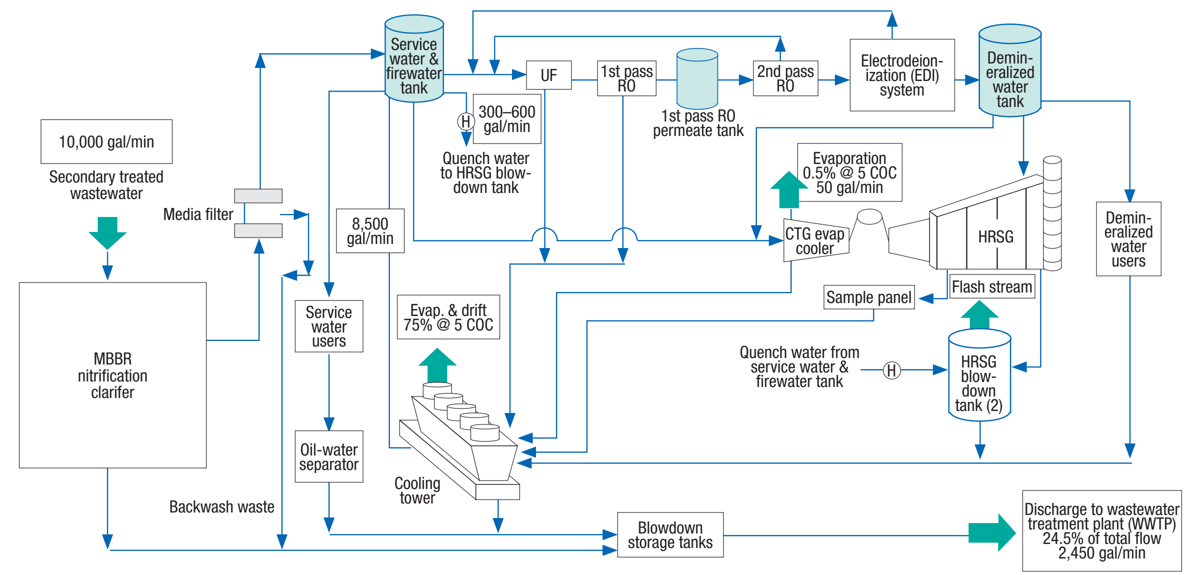

FIGURE 3. **This is an example of a water balance for an MBBR and clarifier system**

COC: cycles of concentration; CTG: combustion turbine generator; HRSG: heat recovery steam generator; H: stream number

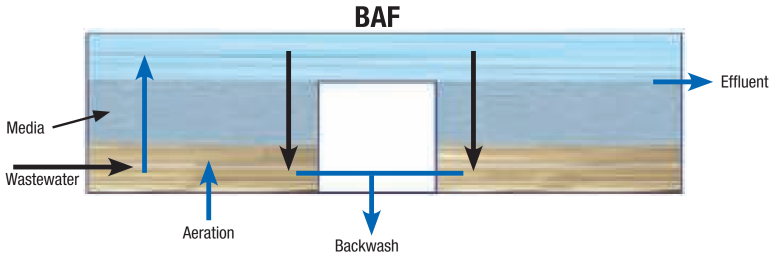

FIGURE 4. The biological aerated filter (BAF) is a high-flow, fixed-film, biological wastewater-treatment system that removes both suspended and dissolved organic material found in wastewater

is a high-flow, fixed-film, biological wastewater-treatment system that removes both suspended and dissolved organic material found in wastewater. Some vendors combined the fixed-film and dynamic media within this system.

Secondary treated wastewater from the POTW enters the bottom of a submerged, upflow-aerated biological filter made of granular media, which physically removes suspended solids and dissolved pollutants. The media provides surface area for the growth of nitrifying bacteria that assimilate ammonia. Overflow effluent is sent to the service-water or plant-water tank. Effluent quality is typically BOD 10–20 mg/L, TSS 10–20 mg/L, and NH_3-N less than 3 mg/L.

The BAF is smaller than the MBR and the MBBR. Capacity of the unit can be increased by increasing the media bed height. Because of the high TSS from the BAF, disk filtration is required before sending the effluent to the service-water or plant-water tank, similar to the MBBR process shown in Figure 3. However, BAF does not handle influent BOD and TSS variations.

The major benefits and liabilities of the BAF are given in Table 4. Although BAF is applied to tertiary treated (Title 22 of the California Code of Regulations) wastewaters for ammonia removal, it is not preferred for treatment of the secondary treated wastewaters.

Alternative treatments

Of course, the bioreactors can be replaced by a clarifier, filtration and chemical addition. Although this is the lowest capital-cost system, the amount of chemicals required and operating cost make this infeasible and unsustainable in the longterm due to severe biofouling issues. The estimated chemical dosage rates compared to the MBR are as follows: corrosion-inhibitor rate doubles, mineral dispersant rate is increased 1.5 times, and the rate of sodium hypochlorite/sodium bisulfate is 10 times. Fouling is expected and annual unplanned 72-h shutdowns are anticipated for pressure washing cooling-tower fills with hydrogen peroxide or bleach. The unplanned shutdown cost will quickly pay off investments in bioreactor systems.

Case study

Figure 5 shows a rather complex application of a revamp for an ex-

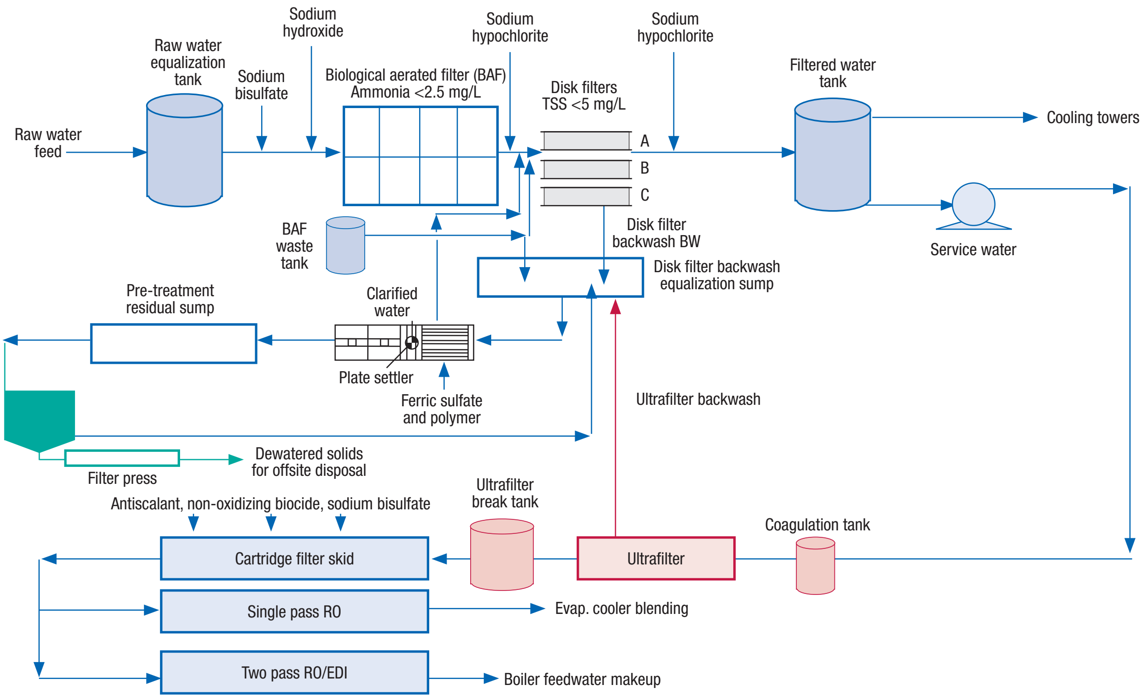

FIGURE 5. This rather complex application of a revamp for an existing BAF is discussed in the case study

TABLE 4. ADVANTAGES AND DISADVANTAGES OF THE BIOLOGICAL AERATED FILTER (BAF)	
BAF Advantages	**BAF Disadvantages**
1. Applicable to limited spaces 2. Lower power consumption 3. Handles temperature variations 4. Very small footprint	1. Requires clarification, disk filtration and/or multi-media filtration 2. Does not handle influent variability 3. Ultrafiltration needed for demineralization system 4. Backwash needs to be dewatered or thickened further

isting BAF. Makeup for the demineralized water-treatment system is secondary-treated municipal wastewater. This water undergoes further processing at the industrial plant (in this example, a power plant), including biological treatment primarily to remove ammonia and disk filtration to remove suspended solids. However, the cartridge filters for the reverse osmosis and electrodeionization (RO/EDI) system were severely fouled because of submicron particles (<1 µm) passing through the disk filter. An ultrafilter was proposed to be installed to protect the RO/EDI system.

There are two ways to handle the sludge generated from the treatment process: (1) discharging the thickened sludge to the POTW, and (2) landfilling the thickened and filter-pressed sludge. In the current case, a parallel-plate gravity-settler unit was designed to precipitate suspended solids from equalized filter backwash wastewater and the plate settler sludge was pumped back to the POTW. An additional thickener and filter press were proposed to process the plate settler sludge. The produced cake from the dewatering system can be landfilled at a nearby facility.

The proposed dewatering system utilizes a solids gravity thickener followed by a sludge conditioning tank and a filter press. The solids thickener will process residuals continuously, while the sludge conditioning tank and filter will operate on a batch basis (as needed). ■

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References

1. Morton, Robert and others, Advanced Water Treatment of Non-nitrified Secondary Effluent with Tertiary Membrane Bioreactor and Reverse Osmosis Processes, WEFTEC 2013 Conference Proceedings, 86th Annual Water Environment Federation Technical Exhibition and Conference, Chicago, October 5 to 9, 2013. http://weftec2013.conferencespot.org/55109-wefb-1.1182180/t-022-1.1185426/522-1.1185475/a-485-1.1185494
2. Bartels, Craig and others, Operational Performance and Optimization of RO Wastewater Treatment Plants, Hydranautics, Technical Papers. http://www.membranes.com/index.php?pagename=tech_papers
3. Morton, Robert, and others, Pilot Study of Advanced Treatment Processes to Recycle JWPCP Secondary Effluent, Proceedings of the Water Environment Federation, WEFTEC2011: Session 41 through Session 50, pp. 2979-2994(16). http://www.ingentaconnect.com/content/wef/wefproc/2011/00002011/00000014/art00046?crawler=true
4. U.S. Environmental Protection Agency (EPA), "Water: Effluent Guidelines," http://water.epa.gov/scitech/wastetech/guide/
5. UN Water website, The United Nations Inter-Agency Mechanism on all Freshwater Related issues, Including Sanitation, http://www.unwater.org/statistics/en/

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Solids Discharge: Characterizing Powder and Bulk Solids Behavior

How shear-cell testing provides a basis for predicting flow behavior

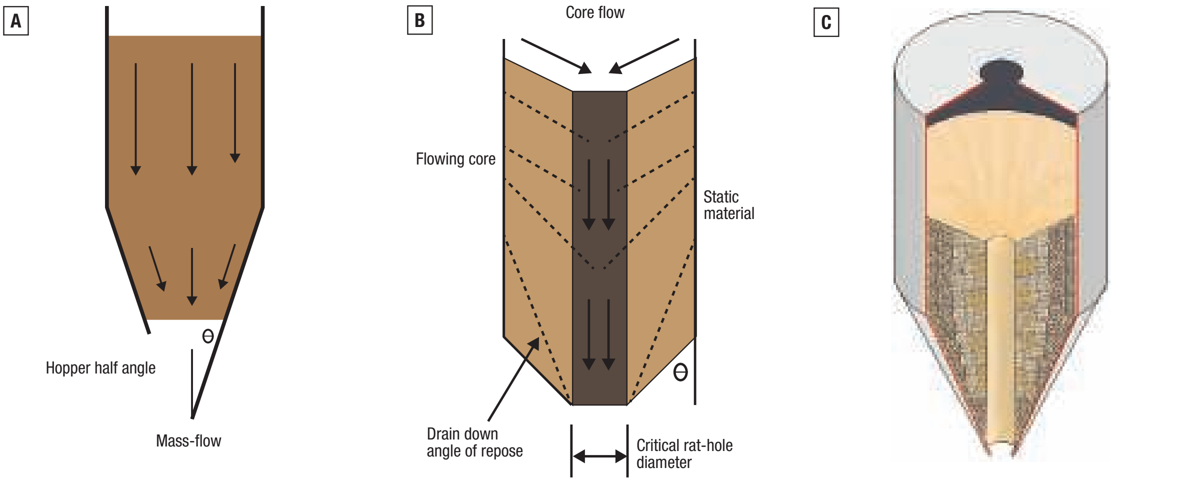

FIGURE 1. Three common types of flow behavior for powder in a bin are mass flow (1a), core flow or funnel flow (1b) and rathole formation (1c)

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Powder jams are the once-in-a-month catastrophe that can bring processing operations to a standstill. Whether it's erratic flow behavior or complete stoppage of powder discharge, the consequence is the same. Shutdown may be necessary before startup can take place. Why? Formulations often involve multiple component powders blended together. If the flow becomes disrupted, one of the possible consequences is segregation of components. Smooth and continuous flow of powder from start to finish is the operating goal to minimize the onset of other problems like segregation.

Traditional testing techniques used to predict flow performance, such as flow cup, angle-of-repose measurement and tap test, actually have limited relevance to whether a powder will flow. They are relatively affordable in terms of equipment purchase and easy for operators to use. The data, however, do not predict whether reliable discharge will take place from the storage vessels containing the powder.

Shear cells for testing powder flow have been used in the minerals industry for decades. Recent improvements in the design of this equipment and the processing power available in today's personal computers (PCs) make them more affordable and user friendly. The bottom line is that shear cells can predict powder flow behavior using a proven scientific principle that measures inter-particle sliding friction. Mathematical calculations embedded in the software used with shear cells provide estimates for "arching dimension" in mass flow and "rathole diameter" in core flow. These values become design limits for hopper openings and half angle.

This article addresses the rheology of powder-flow behavior and explains how the shear cell is used to make these types of powder measurements and calculations for storage equipment design (see also, "A pragmatic Approach to Powder Processing," *Chem. Eng.*, August 2015, pp. 59–62).

Types of powder flow

In a perfect world for powder processors, "mass flow" would take place all the time when powder discharges from a container. Figure 1a shows how particles move uniformly downward in lockstep with one another as the fill level in the bin reduces. The fundamental principle is referred to as "first in, first out." One obvious advantage is that blends of powders retain their component ratio without segregation. This is one of the most important considerations for formulators who must ensure that final product has the intended makeup as designed in research and development (R&D).

More typical of powder processing in most plant operations is "core flow" or "funnel flow" as shown in Figure 1b. Particles at the top of the container move toward the center and then downward through the middle, discharging out the hopper well before the powder that had been further down in the vessel. Larger particles have a tendency to move more readily than smaller particles, potentially resulting in segregation. This type of behavior is called "last in, first out." One possible unfortunate consequence is that powder around the outer wall of the vessel becomes stagnant, consolidates over time,

FIGURE 2. The flow cup test is relatively easy to setup and perform, and the data are used to calculate the Carr index, Equations (1), and Hausner ration, Equation (2)

and then becomes lodged in place. This type of structure is referred to as a "rathole" shown in Figure 1c. The rathole may extend from top to bottom of the bin and may change in diameter of opening as a function of powder depth.

Processors prefer mass flow for obvious reasons. Cohesive materials will generally exhibit core flow in plant equipment as originally designed. The hopper wall angle and its material of construction have a direct impact on flow behavior. Therefore the challenge is to manage the problem with the equipment that exists, which means modifying the formulation, or redesigning the bin equipment, if practical.

Traditional tests for flowability

As mentioned earlier, there are three common methods for predicting flow: flow cup, angle of repose and the tap test.

Flow cup. The most popular testing method is the flow cup, which is quick and easy to use. The cup is basically an open cylinder with a removable disc that is inserted into the bottom (Figure 2). A family of discs, each with a different hole diameter in the middle, is provided with the cup. Once the disc is in place, the cup is filled with powder and the operator observes whether the material discharges through the hole. Processors may know from experience what difficulties they are likely to face depending on the hole diameter that is needed to allow the powder to discharge from the cup. In a practical sense, this instrument is used as a "go" or "no-go" indicator for powder processing on a regular basis.

Angle of repose. This is a simple test method that observes powder in a pile and measures the angle of the pile relative to horizontal. Note that both the angle-of-repose method and the flow-cup test work with powders that are loosely consolidated. They do not attempt to evaluate the powder as it settles, which is what happens when powder is placed in a containment vessel of any kind. This phenomenon, called "consolidation," is an important distinction to keep in mind because it has direct impact on how flow behavior can change.

Tap test. The tap test takes a cylinder of powder and shakes it to determine how much settling will occur. The change in volume of the powder from start to finish is a measurement of the powder's tendency to consolidate. The "loose fill" density, ρ_{poured}, of the powder at the start of the test is calculated by dividing the cylinder volume into the weight of the sample. The "tap density," ρ_{tapped}, is calculated by dividing the reduced volume of powder at the end of the test into the sample weight. The two density values are compared to one another, giving an indicator for the consolidation that can take place over time when the powder settles. Two standard calculations that are typically used by industry to evaluate tap test data are called Carr Index (*Carr%*) and Hausner Ratio (*HR*), as defined in Equations (1) and (2):

$$Carr\,\% = \left(\frac{\rho_{tapped} - \rho_{poured}}{\rho_{tapped}}\right) \times 100 \quad (1)$$

$$HR = \left(\frac{\rho_{poured}}{\rho_{tapped}}\right) \quad (2)$$

Shear cell test for flowability

Shear cells measure the inter-particle friction of powder materials. This type of test has direct application to predicting flow behavior in gravity discharge for powders stored in vessels of any kind. Shear cells were

FIGURE 3. For shear-cell testing, powder is placed into a ring-shaped trough for annular shear cell (3a), which is placed into a commercial powder flow tester (3b), which uses either a vane lid (3c) or a wall-friction lid (3d)

first applied to powders and bulk solids in the minerals industry over 50 years ago. More recent advancements in the use of computers to automate testing and improvements in shear cell design have allowed this type of instrument to become more commonplace throughout the powder-processing industries.

The current popular design is the annular shear cell. Powder is placed into a ring-shaped cell called the "trough," shown in Figure 3a, weighed in order to calculate the "loose fill" density, and then placed onto a test instrument such as that shown in Figure 3b. The lid, which will fit on top of the cell, is attached to the upper plate on the instrument and can be one of two types:

1. The *vane lid* (Figure 3c) has individual pockets separated by vanes.
2. The *wall-friction lid* (Figure 3d) is a flat surface and is made of material similar to the hopper wall in the powder storage vessel on the production floor. Examples might include mild steel, stainless steel or Tivar.

Basic operation of the instrument during the test procedure is to bring the lid down onto the powder sample and compress the material to a specified pressure. This action consolidates the powder, forcing the particles to move closer to one another. With the powder in this compressed state, the trough rotates at a low speed — perhaps 1 rpm. The following is observed, depending on the lid in use:

1. The vane lid, which is attached to a torsional spring, rotates with the trough as long as the frictional force between powder particles is greater than the torsion in the spring. When the lid stops moving with the trough, the torsion in the spring exceeds the inter-particle friction. The moment when this stoppage in lid movement takes place defines the yield stress between powder particles and is a measure of what is referred to as "failure strength" of the powder.
2. The wall-friction lid behaves in a similar fashion to the vane lid while measuring the sliding friction between the powder particles and the surface material of the lid. When rotation of the wall lid stops during the test, the yield stress for powder flow on this particular surface is established.

Movements of trough and lid during the shear-cell test are very small and almost unobservable to the naked eye. Increasing consolidating pressures are applied to the powder sample to construct a picture of how the powder's failure strength will change. This equates with vessels that have increasing fill levels of material.

Three key graphs

Basic tests run with the shear cell address flow behavior of powder in gravity discharge from a storage vessel. The following summarizes the three primary graphs used to characterize flow characteristics.

Flow function. The flow-function test evaluates the ability of the powder to form a cohesive arch in the hopper that could restrict or prevent flow out the opening in the bottom. Result-

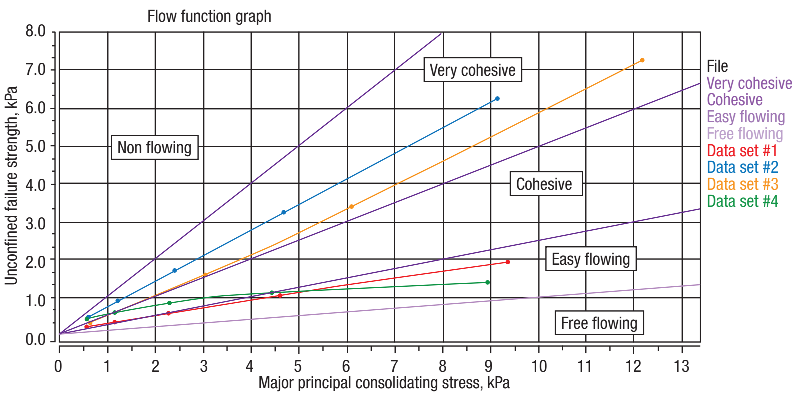

FIGURE 4. The flow-function graph shows how the failure strength for the powder changes as a function of increasing consolidating stress

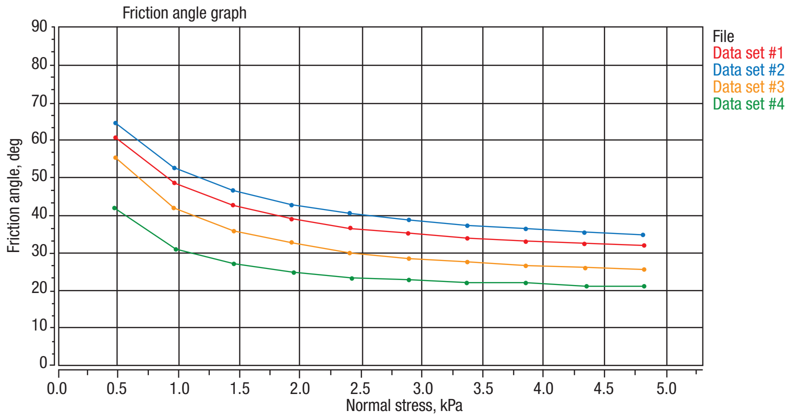

FIGURE 5. Data from the wall-friction test show how the effective friction angle for the hopper wall to allow gravity-driven powder flow on its surface changes as a function of consolidating stress

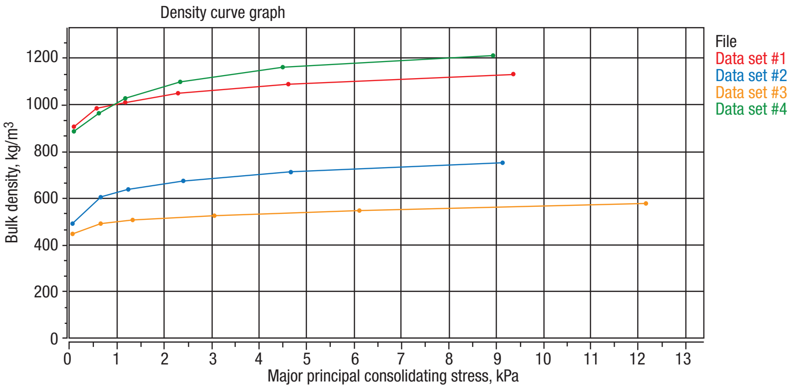

FIGURE 6. The density of a powder in a vessel will vary depending on the consolidating stress, which in turn is a function of the fill level

ing data form the flow-function graph (Figure 4), which shows how the failure strength for the powder changes as a function of increasing consolidating stress (height of powder-fill level in the vessel). Industry has agreed to classify regions of flow behavior as shown in the figure, ranging from "free flowing" to "non-flowing." As might be expected, many powders exhibit "cohesive" or "very cohesive" flow and are likely to be problematical in terms of processability.

Wall friction. The wall-friction test measures the flowability of the powder on the material comprising the hopper wall. Data from the wall-friction test (Figure 5) show how the effective friction angle for the hopper wall to allow gravity-driven powder flow on its surface changes as a function of consolidating stress (height of powder-fill level in the vessel). Experience indicates that friction angles below 15 deg will have relatively easy flow behavior whereas friction angles above 30 deg will be cause for concern. Data from this test may also have some correlation with findings obtained in the angle-of-repose test described earlier in this article.

Density. Density of powder in a vessel will vary depending on the consolidating stress, which in turn is a function of the fill level. Figure 6 shows an example. If the change in density increases by more than 50% relative to the "loose fill" condition, then there is an expectation that flow problems may exist. Note that the density test will very likely have a point on the curve that correlates with the findings in the tap test described earlier in this article.

Data analysis

Parameters of interest that can be calculated from the data in the above tests include the following:

1. The *arching dimension* is the length of a bridge section that the powder has sufficient strength to create in the hopper section of a vessel. If the bridge is longer than the dimension of the opening, flow restrictions may result.
2. The *rathole diameter* is the potential diameter of a hole in the center of the vessel through which powder will move when the type of behavior is "core flow." The rathole diameter may change in value as a function of the powder depth in the vessel. Powder particles that are located radially outside of this diameter dimension may become lodged in place over time and potentially not flow at all.
3. *The hopper half angle* is the required angle — relative to vertical in the hopper section — that is needed to achieve mass flow behavior.

These three values can be used for the design of powder storage equipment or to characterize reference powders that constitute benchmarks for future production batches.

Concluding remarks

Shear cells provide a scientific basis for analytically predicting flowability of powder in gravity discharge. Their use is becoming more accepted because improved designs for the instrument make them affordable, user friendly, and automatic in operation under control of a computer. The most notable change in the past year is the reduction in time needed to run a standard flow-function test from 45 min to 15 min. Productivity gains with the current generation of instrumentation certainly give rise to their potential use in quality control as well as R&D. The chemical process industries on the whole view the shear cell as an important tool for improving rapid scaleup of new formulations into full production. ■

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All photos courtesy of Brookfield Engineering Laboratories, Inc.

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A Universal Equation for Designing Pipelines

The pipe-flow equation presented here can be used to properly and easily size pipelines for liquid, vapor and two-phase flow. Example calculations are also shown

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Sizing pipelines is a fundamental task for design engineers, who typically use several equations to size pipes for different flows (liquid/vapor/two-phase). The flow equations, however, are basically analogous. Incompressible flow calculations are considered relatively simple and easy to do. However, a major challenge faced by design engineers is sizing a pipe flow that experiences significant variations in the flow density and velocity.

Generally, calculations for vapor or two-phase piping often involve repetitive calculations for accurate results. Sizing a pressure-relief system that operates at very high velocity and high pressure drop is a difficult application. Vapor flow and two-phase flow in relief-discharge piping involve rapid changes in density that result in very high line velocities. The calculation methods of the American Petroleum Institute (API) have been widely used in industries for sizing relief system piping [*1*]. For vapor flow, the relatively conservative isothermal equation is recommended. And if the pipe system handles vapor and flashing or non-flashing liquid, the homogeneous equilibrium equation is suggested. Consequently, emergency-relief-system designers use several pipe-flow equations to size relief system pipes [*1*].

This article presents a universal pipe-flow equation to properly and easily size pipe lines for liquid flow, vapor flow and two-phase flow, and suggests appropriate and convenient calculation procedures. The universal equation for pipe flows is developed by modifying a universal mass-flux equation for sizing relief valves previously developed by Kim and others [*2*]. This article provides an overview of the pipe flow equations and highlight the key considerations. Additionally, four example calculations are provided to illustrate the application of the universal equation for pipe flows.

Review of existing equations

Those who design pipelines that are intended for fluid transportation are expected to cope with the calculation of pressure drop in a piping system. Pressure losses consist of three different components for a pipe system at a given velocity. Generally, total pressure loss in the pipe system is the sum of friction loss, acceleration loss and elevation loss, as shown in Equation (1). However, Equation (1) does not precisely represent vapor and two-phase systems that involve an additional compression term.

NOMENCLATURE

C_1	Constant in Equation (7), 24
C_2	Constant in Equation (7), 2.898× 10^6
D	Pipe inner diameter, ft
G	Mass flux, lb/s-ft^2
f	The Fanning friction factor
g	Acceleration of gravity, ft/s^2
L	Equivalent pipe length, ft
M	Mass flowrate, lb/h
N	Total pipe loss coefficient
n_1	P_1/P_0 in Equation (7)
n_2	P_2/P_0 in Equation (7)
P	Absolute pressure, psia
v	Specific volume, ft^3/lb
Z	Elevation, ft
α, β, ω	Parameters for a pressure-specific volume correlation
ρ	Density, lb/ft^3
Subscripts	
0,1,2	Physical property data states
avg	Arithmetic average
ec	Equivalent choked (critical) conditions

$$\Delta P_{total} = \Delta P_{friction} + \Delta P_{acceleration} + \Delta P_{elevation} \quad (1)$$

For the friction loss term, one of the most useful and important equations is the Darcy-Weisbach equation, Equation (2).

$$\Delta P_{friction} = \frac{1}{2 \cdot \rho_{avg}} G^2 \cdot N \quad (2)$$

Equation (2) is often expressed in terms of average specific volume [*3*]. Therefore, the friction losses in pipelines can be computed directly using Equation (2) or Equation (3).

$$\Delta P_{friction} = \frac{v_{avg}}{2} G^2 \cdot N \quad (3)$$

Although the two equations seem to be identical, they give different results when applied to vapor and two-phase flows because the average density is not the reciprocal of the average specific volume. Equation (3) has been found to generally over-predict friction losses where the change in density is significant. However, the over-prediction decreases with an increase in the number of pipe segments with Equation (3). This indicates that Equation (3) should be used on a pipe segment-by-segment basis. On the other hand, Equation (2) should be based on the entire pipeline in one calculation, rather than a pipe segment-by-segment basis in numerous calculations.

Equation (4), which accounts for the three pressure loss terms including a compressible term, is a general homogeneous equilibrium model for pipe flows [*4–5*]. This general equation can be derived by integrating the Bernoulli equation.

$$G^2 = \frac{\int_{P1}^{P2} \frac{-dP}{v} + \rho_{avg}^2 g \cdot (Z_1 - Z_2)}{\ln \frac{v_2}{v_1} + \frac{N}{2}} \quad (4)$$

Equation (5) is an isothermal vapor-flow equation based on the inlet Mach number. On the other hand, Equation (6) is based on the outlet Mach number. The sizing of relief discharge piping at a given outlet pressure is generally performed with Equation (6), calculating back through the piping system to verify actual backpressure at each pressure relief device. For non-ideal gases, an incremental or stepwise approach is usually required to account for the changes in compressibility factor. API recommends this isothermal vapor equation that results in slightly more conservative predictions for most cases [*1*].

$$\frac{f \cdot L}{D} = \frac{1}{M_{a1}^2}\left[1 - \left(\frac{P_2}{P_1}\right)^2\right] - \ln\left(\frac{P_1}{P_2}\right)^2 \quad (5)$$

$$\frac{f \cdot L}{D} = \frac{1}{M_{a2}^2}\left[\left(\frac{P_1}{P_2}\right)^2\right]\left[1 - \left(\frac{P_2}{P_1}\right)^2\right] - \ln\left(\frac{P_1}{P_2}\right)^2 \quad (6)$$

If the system handles mixed phase fluids, the sizing calculations are complex. Equation (7) is generally used to determine pressure drop in multi-phase systems for a horizontal line [*1, 6*]. This equation is based on the homogeneous equilibrium-flow assumption to determine line pressure losses caused by friction and acceleration terms. Performing an isenthalpic flash for the pressure ranges of interest is required. However, Equation (7) can also be used for single liquid or vapor flow.

$$C_1 \frac{f \cdot L}{D} = \frac{C_2 \cdot P_R \cdot \rho_R}{G^2}\left[\frac{n_1 - n_2}{1-\omega} - \frac{\omega}{(1-\omega)^2}\ln\left(\frac{(1-\omega)n_1 + \omega}{(1-\omega)n_2 + \omega}\right)\right] + \ln\left[\frac{(1-\omega)n_1 + \omega}{(1-\omega)n_2 + \omega}\left(\frac{n_2}{n_1}\right)\right] \quad (7)$$

All the existing equations above that are based on the same derivation from the Bernoulli equation are technically identical. Although Equations (4) through (7) are widely used in industry, Kim and Singh presented a new model for pipe flows to correct an inherent problem with those equations that the acceleration term was not considered appropriately [*8–9*]. The new model for pipe flows that corrected the acceleration term, including compression term, has improved the calculation accuracy. Using an average specific volume for the acceleration term is necessary to correct the problem identified by Kim and Singh [*8–9*].

A universal equation

As a fluid flows through a pipe, the flow is resisted by pipe friction and the specific volume and kinetic energy increase. Several factors affect the friction loss in pipes: the density and viscosity of the fluid being handled; the size of the pipes; the roughness of the pipe internal surface; the length of the pipe; and fittings in the pipe. The friction factor of *f* in Equations (4) through (7) can be calculated from the Reynolds number of the flow and the relative roughness of the pipe. For simplicity, it is assumed that frictional losses in the piping system are constant to develop a pipe flow equation. This means that the total pipe frictional resistance factor of *N* is independent of the Reynolds number. This article does not include the details on how to calculate the friction factor, because many accurate and convenient equations are available for evaluating the friction factor. The changes in elevation within the system and the changes in the specific volume of the fluid also contribute to the total pipe frictional losses.

However, the changes in temperature are relatively small for most cases. Therefore, the pipe flow can be considered isenthalpic. By the way, either an isenthalpic flow path or an isentropic flow path can be modeled for a universal equation for pipe flows. For flashing two-phase flow, equilibrium flashing conditions are considered achieved if the pipe length is longer than the minimum required length of 4 in. for equilibrium [*7*]. Therefore, the homogeneous equilibrium model (HEM) based on the isenthalpic flow path is popular because this model yields a conservative design.

The universal equation for pipe flows is based on the following conservative and valid assumptions:

- The flow is steady
- The flow is one-dimensional
- The flow is in thermal equilibrium
- The flow is homogeneous
- The system is isenthalpic
- The fluid has a Newtonian flow behavior
- A pressure and specific volume correlation fits the data well

The universal equation for pipe flows, Equation (8), is developed by modifying a universal mass-flux equation for sizing relief valves [*2*]. However, Equation (8) is not applicable for sub-cooled flashing flow.

$$G = 68.07\sqrt{\frac{P_{ec}^{\ \beta+1}}{\alpha \cdot \beta \cdot P_0^{\ \beta} \cdot v_0}} \quad (8)$$

Where:

$$P_{ec} = \left[\frac{1}{2\cdot\alpha\cdot\beta\cdot P_0{}^{\beta}\cdot v_0 (P_1 - P_2 + \rho_{avg}(Z_1 - Z_2)/144)} \left(\frac{A\cdot v_0{}^2}{v_{avg}} + \frac{N}{\rho_{avg}} \right) \right]^{\frac{-1}{\beta+1}} \quad (9)$$

$$A = \left(\alpha \left(\frac{P_0}{P_2} \right)^{\beta} - \alpha + 1 \right)^2 - \left(\alpha \left(\frac{P_0}{P_1} \right)^{\beta} - \alpha + 1 \right)^2 \quad (10)$$

As shown in the equations above, average density and average specific volume determine the mass flux for a given piping system. Therefore, a pressure and specific-volume correlation, Equation (11), is a crucial component of the universal equation that enables design engineers to complete a pipe-sizing task with only a few flash calculations. Kim and others presented the details on how to determine the two parameters (alpha and beta) in Equation (11) [2].

$$v = v_0 \left[\alpha \left(\frac{P_0}{P} \right)^{\beta} + (1 - \alpha) \right] \quad (11)$$

Two important values in Equation (9), average density and average specific volume, can be obtained by taking an arithmetic mean value of the densities or specific volumes over about 15 segments that are based on a constant pressure interval. However, the average specific volume and the average density can also be estimated using Equations (12) and (13), respectively. Equation (12) results in the best average specific volume. Equation (13) was derived from Equation (7) and is used to calculate accurate average density. One should be aware that Equation (13) requires an omega value or alpha value if beta is almost 1.0 (alpha = omega). The omega value should be based on the data at P_0 and 50% of P_0. Although Equation (13) provides very accurate results if the pressure-density correlation with omega fits well, the arithmetic mean density using Equation (11) is generally more reliable. The accuracy of the pipe flow equation is closely related to the accuracy of the specific volume prediction in a piping system. Thus, it is essential for the pipe-flow equation to have a good correlation of pressure and specific volume.

$$v_{avg} = \frac{v_0}{P_1 - P_2} \left[\frac{\alpha\cdot P_0^{\beta}}{1-\beta} \left(P_1^{1-\beta} - P_2^{1-\beta} \right) + (1-\alpha)(P_1 - P_2) \right] \quad (12)$$

$$\rho_{avg} = \frac{P_0}{(P_1 - P_2)\cdot v_0} \cdot \left\{ \frac{\eta_1 - \eta_2}{1-\omega} - \frac{\omega}{(1-\omega)^2} \ln\left[\frac{(1-\omega)\eta_1 + \omega}{(1-\omega)\eta_2 + \omega} \right] \right\} \quad (13)$$

For a case of known flowrate, Equation (14) is used to predict the downstream pressure. Before solving Equation (14), one should first calculate P_{ec} using Equation (16). The final downstream pressure is obtained by repetitive calculation when both P_2 in the right side and left side are close enough. On the other hand, Equation (15) is used to predict the upstream pressure. The calculation procedures are exactly the same as for predicting the downstream pressure.

$$P_2 = P_1 + \frac{\rho_{avg}(Z_1 - Z_2)}{144} - \left[\frac{1}{2\cdot\alpha\cdot\beta\cdot P_0^{\beta}\cdot v_0} \left(\frac{A\cdot v_0{}^2}{v_{avg}} + \frac{N}{\rho_{avg}} \right) \right] \cdot P_{ec}^{\beta+1} \quad (14)$$

$$P_1 = P_2 - \frac{\rho_{avg}(Z_1 - Z_2)}{144} + \left[\frac{1}{2\cdot\alpha\cdot\beta\cdot P_0^{\beta}\cdot v_0} \left(\frac{A\cdot v_0{}^2}{v_{avg}} + \frac{N}{\rho_{avg}} \right) \right] \cdot P_{ec}^{\beta+1} \quad (15)$$

Where:

$$P_{ec} = \left[\alpha\cdot\beta\cdot P_0^{\beta}\cdot v_0 \left(\frac{G}{68.07} \right)^2 \right]^{\frac{1}{\beta+1}} \quad (16)$$

Example calculations

In order to illustrate the use of the universal equation for pipe flows, the authors considered the following four examples handling normal hexane at the reference pressure (P_0) of 314.7 psia. The piping system is at a constant pipe inside diameter of 3.068 in. (0.2557 ft). A constant Fanning friction factor of 0.00445 is assumed with a total equivalent piping of 143.6 ft. For better accuracy, one can estimate the average friction factor using one of the well-proven pipe-friction correlations that requires additional average viscosity information. One should define a simple polynomial equation where viscosity varies with pressure.

The total pipe loss coefficient, *N,* is calculated to be 10, as shown here:

$$N = \frac{4\cdot f\cdot L}{D} = \frac{4\cdot 0.00445\cdot 143.6}{0.2557} = 10$$

Example 1. Mass flowrate of liquid at 60°F with known upstream and downstream pressures. Calculate the mass flowrate when the pipe inlet pressure (P_1) and outlet pressure (P_2) are 314.7 psia and 14.7 psia, respectively. The piping system has a vertical elevation rise of 20 ft. Assume no density change for liquid flow. All input data and the results are summarized in Table 1.

First, calculate the P_{ec}. A lower P_{ec} value than 14.7 psia means that the system is not choked.

$$P_{ec} = \left[\frac{1}{2\cdot\alpha\cdot\beta\cdot P_0{}^{\beta}\cdot v_0(P_1 - P_2 + \rho_{avg}(Z_1 - Z_2)/144)}\right.$$

$$\left.\left(\frac{A\cdot v_0{}^2}{v_{avg}} + \frac{N}{\rho_{avg}}\right)\right]^{\frac{-1}{\beta+1}} = 0.0948\ psia$$

Where:

$$A = \left(\alpha\left(\frac{P_0}{P_2}\right)^{\beta} - \alpha + 1\right)^2 - \left(\alpha\left(\frac{P_0}{P_1}\right)^{\beta} - \alpha + 1\right)^2 = 0.0099$$

Second, calculate the *G*.

$$G = 68.07\sqrt{\frac{P_{ec}{}^{\beta+1}}{\alpha\cdot\beta\cdot P_0{}^{\beta}\cdot v_0}} = 68.07$$

$$\sqrt{\frac{0.0948^{0.00008+1}}{20.15339\cdot 0.00008\cdot 314.7^{0.00008}\cdot 0.024019}}$$

$$= 3{,}366.84\ lb/s - ft^2$$

Third, calculate the mass flowrate.

$$M = G\cdot\frac{\pi}{4}D^2\cdot 3{,}600 = 3{,}366.84\cdot\frac{3.1416}{4}\cdot 0.2557^2$$

$$\cdot 3{,}600 = 622{,}411\ lb/h$$

Example 2. Mass flowrate of vapor at 314.7 psia and 413°F with known upstream and downstream pressures. Calculate the mass flowrate when the pipe inlet pressure (P_1) and outlet pressure (P_2) are 250 psia and 100 psia, respectively. The piping system has a vertical elevation rise of 20 ft. All input data and the results are summarized in Table 1.

First, calculate the P_{ec}. The P_{ec} calculation requires average density and average specific volume. A P_{ec} value that is lower than 100 psia means that the system is not choked.

$$P_{ec} = \left[\frac{1}{2\cdot\alpha\cdot\beta\cdot P_0{}^{\beta}\cdot v_0(P_1 - P_2 + \rho_{avg}(Z_1 - Z_2)/144)}\right.$$

$$\left.\left(\frac{A\cdot v_0{}^2}{v_{avg}} + \frac{N}{\rho_{avg}}\right)\right]^{\frac{-1}{\beta+1}} = 71.8660\ psia$$

Where:

$$A = \left(\alpha\left(\frac{P_0}{P_2}\right)^{\beta} - \alpha + 1\right)^2 - \left(\alpha\left(\frac{P_0}{P_1}\right)^{\beta} - \alpha + 1\right)^2 = 20.2727$$

$$v_{avg} = \frac{v_0}{P_1 - P_2}\left[\frac{\alpha\cdot P_0{}^{\beta}}{1-\beta}\left(P_1{}^{1-\beta} - P_2{}^{1-\beta}\right) + (1-\alpha)(P_1 - P_2)\right]$$

$$= 0.5063\ ft^3/lb$$

$$\eta_1 = \frac{P_1}{P_0} = \frac{250}{314.7} = 0.7944$$

$$\eta_2 = \frac{P_2}{P_0} = \frac{100}{314.7} = 0.3178$$

$$\rho_{avg} = \frac{P_0}{(P_1 - P_2)v_0}\cdot\left\{\frac{\eta_1 - \eta_2}{1-\omega} - \frac{\omega}{(1-\omega)^2}\right.$$

$$\left.\ln\left[\frac{(1-\omega)\eta_1 + \omega}{(1-\omega)\eta_2 + \omega}\right]\right\} = 2.2066\ lb/ft^3$$

Second, calculate the *G*.

$$G = 68.07\sqrt{\frac{P_{ec}{}^{\beta+1}}{\alpha\cdot\beta\cdot P_0{}^{\beta}\cdot v_0}} = 68.07$$

$$\sqrt{\frac{71.8660^{0.97744+1}}{1.80580\cdot 0.97744\cdot 314.7^{0.97744}\cdot 0.193803}}$$

$$= 479.41\ lb/s - ft^2$$

Third, calculate the mass flowrate.

$$M = G\cdot\frac{\pi}{4}D^2\cdot 3{,}600 = 479.41\cdot\frac{3.1416}{4}\cdot 0.2557^2$$

$$\cdot 3{,}600 = 88{,}626\ lb/h$$

Example 3. Inlet pipe pressure of vapor at 314.7 psia and 413°F with known downstream pressure and flowrate. Calculate the inlet pipe pressure when 20,000 lb/h vapor is flowing into a vessel operating at 14.7 psia. The piping system has no vertical piping section. All input data and the results are summarized in Table 1.

First, calculate the *G*.

$$G = M\cdot\frac{4}{\pi\cdot D^2\cdot 3600} = 20{,}000\cdot$$

$$\frac{4}{3.1416\cdot 0.2557^2\cdot 3600} = 108.19\ lb/s - ft^2$$

Second, calculate the P_{ec}. The higher P_{ec} than the vessel operation pressure of 14.7 psia means that the flow is choked at 15.9452 psia. So, the pipe inlet pressure should be calculated with the pipe outlet pressure of 15.9452 psia.

TABLE 1. A SUMMARY OF EXAMPLE CALCULATIONS				
Parameter	Example 1	Example 2	Example 3	Example 4
v_0 at 314.7 psia, ft^3/lb	0.024019	0.193803	0.193803	0.037478
v at 164.7 psia, ft^3/lb	0.024078	0.502851	0.502851	0.286531
v (ft^3/lb) at 14.7 psia	0.024138	6.835644	6.835644	5.76688
α value	20.15339	1.80580	1.80580	7.15817
β value	0.00008	0.97744	0.97744	1.01415
ω value	0.00270	1.75093	1.75093	7.29655
P_{ec}, psia	0.0948	71.8660	15.9452	125.8184
Inlet pressure, psia	314.7	250	64.1	314.7
Outlet pressure, psia	14.7	100	15.9452	227.5
Ave. specific volume, ft^3/lb	0.024019	0.5063	2.8660	0.0841
Ave. density, lb/ft^3	41.6337	2.2066	0.3994	13.6562
Mass flux, $lb/s\text{-}ft^2$	3,366.84	479.41	108.19	919.59
Mass flowrate, lb/h	622,411 lb/h	88,626 lb/h	20,000 lb/h	170,000 lb/h

$$P_{ec} = \left[\alpha \cdot \beta \cdot P_0^{\beta} \cdot v_0 \left(\frac{G}{68.07}\right)^2\right]^{\frac{1}{\beta+1}} = 15.9452\ psia$$

Third, calculate the P_1 with an initial P_1 value (1.05 times P_2). Iterate P_1 calculation with the previous P_1 value until there is no change in P_1. The following is the final calculation after several iterations:

$$P_1 = P_2 - \frac{\rho_{avg}(Z_1 - Z_2)}{144} + \left[\frac{1}{2 \cdot \alpha \cdot \beta \cdot P_0^{\beta} \cdot v_0} \left(\frac{A \cdot v_0^2}{v_{avg}} + \frac{N}{\rho_{avg}}\right)\right] \cdot P_{ec}^{\beta+1} = 64.1\ psia$$

Where:

$$A = \left(\alpha\left(\frac{P_0}{P_2}\right)^{\beta} - \alpha + 1\right)^2 - \left(\alpha\left(\frac{P_0}{P_1}\right)^{\beta} - \alpha + 1\right)^2 = 997.2050$$

$$v_{avg} = \frac{v_0}{P_1 - P_2}\left[\frac{\alpha \cdot P_0^{\beta}}{1-\beta}\left(P_1^{1-\beta} - P_2^{1-\beta}\right) + (1-\alpha)(P_1 - P_2)\right]$$

$$= 2.8660\ ft^3/lb$$

$$\eta_1 = \frac{P_1}{P_0} = \frac{64.1}{314.7} = 0.2037$$

$$\eta_2 = \frac{P_2}{P_0} = \frac{15.9452}{314.7} = 0.0507$$

$$\rho_{avg} = \frac{P_0}{(P_1 - P_2)v_0} \cdot \left\{\frac{\eta_1 - \eta_2}{1-\omega} - \frac{\omega}{(1-\omega)^2} \ln\left[\frac{(1-\omega)\eta_1 + \omega}{(1-\omega)\eta_2 + \omega}\right]\right\} = 0.3994\ lb/ft^3$$

Example 4. Downstream pressure of saturated liquid at 314.7 psia with known upstream pressure and flowrate. Calculate the downstream pressure when the upstream pressure is 314.7 psia at a flowrate of 170,000 lb/h. The system is a horizontal piping. All input data and the results are summarized in Table 1.

First, calculate the G.

$$G = M \cdot \frac{4}{\pi \cdot D^2 \cdot 3,600} = 170,000 \cdot \frac{4}{3.1416 \cdot 0.2557^2 \cdot 3,600} = 919.59\ lb/s\text{-}ft^2$$

Second, calculate the P_{ec}. If the value of P_{ec} is greater than 314.7 psia, the pipe size is to be increased.

$$P_{ec} = \left[\alpha \cdot \beta \cdot P_0^{\beta} \cdot v_0 \left(\frac{G}{68.07}\right)^2\right]^{\frac{1}{\beta+1}} = 125.8184\ psia$$

Third, calculate the P_2 with an initial P_2 value (0.95 times of P_1). Iterate P_2 calculation with the previous P_2 value until there is no change in P_2. The following is a final calculation after several iterations:

$$P_2 = P_1 + \frac{\rho_{avg}(Z_1 - Z_2)}{144} - \left[\frac{1}{2 \cdot \alpha \cdot \beta \cdot P_0^{\beta} \cdot v_0} \left(\frac{A \cdot v_0^2}{v_{avg}} + \frac{N}{\rho_{avg}}\right)\right] \cdot P_{ec}^{\beta+1} = 227.5\ psia$$

Where:

$$A = \left(\alpha\left(\frac{P_0}{P_2}\right)^{\beta} - \alpha + 1\right)^2 - \left(\alpha\left(\frac{P_0}{P_1}\right)^{\beta} - \alpha + 1\right)^2 = 13.3586$$

$$v_{avg} = \frac{v_0}{P_1 - P_2}\left[\frac{\alpha \cdot P_0^{\beta}}{1-\beta}\left(P_1^{1-\beta} - P_2^{1-\beta}\right) + (1-\alpha)(P_1 - P_2)\right]$$

$$= 0.0841\ ft^3/lb$$

$$\eta_1 = \frac{P_1}{P_0} = \frac{314.7}{314.7} = 1.0$$

$$\eta_2 = \frac{P_2}{P_0} = \frac{227.5}{314.7} = 0.7229$$

$$\rho_{avg} = \frac{P_0}{(P_1 - P_2)v_0} \cdot \left\{ \frac{\eta_1 - \eta_2}{1-\omega} - \frac{\omega}{(1-\omega)^2} \right.$$

$$\left. \ln\left[\frac{(1-\omega)\eta_1 + \omega}{(1-\omega)\eta_2 + \omega}\right] \right\} = 13.6562\ lb/ft^3$$

Final remarks

The universal equation for pipe flows, Equation (8), which is based on a homogenous equilibrium model and a Newtonian flow behavior, is simple and useful for designing piping systems as demonstrated in the example calculations. However, as with other general pipe-flow equations, the universal equation cannot be applied to non-equilibrium situations and sub-cooled flashing flow and special handling fluids, such as slurries and non-Newtonian fluids.

"The universal equation for pipe flows presented here is simple and useful for designing piping systems as demonstrated in the example calculations."

This article also examined the existing calculation procedures to develop a new procedure that is convenient and easy to follow as demonstrated in the example calculations. In those cases with significant velocity changes, it is possible that the universal equation based on isenthalpic flash may deviate from the actual flow path. It is well known that the actual pipe flow path is somewhere between isentropic and isenthalpic flow paths. Therefore, the authors are currently developing the calculation procedure for the actual flow path. In the meantime, the universal equation for pipe flows presented in this article can help design engineers complete their assigned tasks with a better understanding of the key parameters in pipe-flow equations, and even manipulate the equation for achieving successful and superior results. ■

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References

1. American Petroleum Institute, "Pressure-relieving and Depressuring Systems," ANSI/API Standard 521, 5th ed., January 2007.
2. Kim, J. S., Dunsheath, H. J., and Singh, N. R., "Sizing Calculations for Pressure-Relief Valves," *Chem. Eng.* February 2013, pp. 35–39.
3. Center for Chemical Process Safety (CCPS), "Guidelines for Pressure Relief and Effluent Handling Systems," AIChE, New York, N.Y., 1998.
4. Darby, R., Size Safety-Relief Valves for Any Conditions, *Chem. Eng.*, September 2005, pp. 42–50.
5. Simpson, L. L., Navigating the Two-Phase Maze, International Symposium on Runaway Reactions and Pressure Relief Design, A. Melhem and H. G. Fisher, eds., Design Institute for Emergency Relief Systems (DIERS), AIChE, New York, meeting held in Boston, Mass., August 1995, pp. 394–417.
6. Leung, J. C., Easily Size Relief Devices and Piping for Two-Phase Flow, *Chem. Eng. Progress*, December 1996, pp. 28–50.
7. Crowl, D. A. and Louvar, J. F., "Chemical Process Safety: Fundamentals with Applications," Prentice Hall, Englewood Cliffs, NJ (1990).
8. Kim, J. S. and Singh, N. R., A Novel Adiabatic Pipe Flow Equation for Ideal Gases, ASME Trans. *J. of Fluids Engineering*, January 2012.
9. Kim, J. S. and Singh, N. R., A Novel Equation for Isothermal Pipe Flow," *Chem. Eng.*, June 2012, pp. 66–70.

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Improving the Operability of Process Plants

Turndown and rangeability have a big impact on the flexibility and efficiency of chemical process operations

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During the design of a chemical process plant, the main focus is on which process units or unit operations must be integrated to convert the feed streams into product stream(s). Design engineers work to achieve this goal; however, in terms of making sure the plant operates smoothly, which is equally important for operation engineers and operators, there are less well-know parameters facing the design engineers.

There are five primary process parameters in each plant — flow, (liquid) level, pressure, temperature, and composition. Composition can be considered a collective term that reflects all parameters (chemical and physical), and provides an indicator of the quality of the stream. Composition can be used to describe the moisture of a gas stream or the octane number of a gasoline stream, or even the electric conductivity of a water stream.

During operation, equipment process parameters generally deviate from the design values (normal level) over time. Five levels can be defined for each process parameter: normal level, high level, high-high level, low level and low-low level. In essence, the operational parameters of a plant relate to the behavior of the plant between the low level and high level of each parameter of the individual equipment components, individual units or the entire plant. In most cases, the operability of a plant can be defined using at least three key parameters: flexibility in operation, resistance against surge (or upset) and the speed of recovery from upset.

Maintaining operating flexibility

Flexibility of operation in this context means the ability of a plant to operate reliably across a wide range of flowrates without sacrificing the overall quantity or quality of product(s).

From a process standpoint, a chemical process plant is a combination of equipment, utility networks and control systems. To design a plant with sufficient flexibility, each of these three elements needs to allow flexibility. Generally speaking, the control system (including control valves and sensors) and utility network should offer the largest amount of operating flexibility, while the equipment itself could offer the lowest amount of flexibility (Figure 1). This requirement for larger flexibility for control items and utility network considerations is important because of the supporting role of the utility system and the controlling role played by instruments in a plant.

Two important concepts are used to quantify flexibility: turndown (TD) ratio and rangeability. These are discussed below, and illustrated in Figure 2.

Turndown ratio

The flexibility of equipment or a plant can be defined using the TD ratio. The most common definition for TD ratio is "ratio of the normal maximum parameter (numerator) to the normal minimum parameter (denominator)." However, the meaning of "normal maximum parameter" and "normal minimum parameter" is not always clear and the interpretation may vary in different companies and plants (This is discussed below).

For an individual equipment component, or multi-component equipment systems, low-flow or low-capacity operation happens frequently over the lifetime of a plant. The reduced-capacity operation may be intentional or accidental.

For instance, reduced-capacity operation could be planned for the purpose of off-loading the equipment for inspection, testing, monitoring,

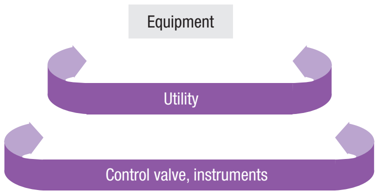

FIGURE 1. Different elements of a plant need different levels of operating flexibility. Since the utility network provides support duty to the equipment, it needs a higher turndown ratio. Control valves and other instruments have a duty to take care of equipment across a wider operating range; thus they require an even higher rangeability

or even to support the shutdown of downstream equipment. But it may also occur accidentally due to, for example, a drop in feed flowrate.

But process plant operators like to know by how much the flowrate of the equipment (and in the larger sense, the entire plant capacity) can be decreased without compromising the process goal or generating off-specification product. Thus, TD ratio can be defined as the ratio of high flow to normal flow, as shown in Equation 1.

$$TD\ ratio = \frac{Q_{High}}{Q_{Low}} \quad (1)$$

Q_{High} = the flowrate of the system at high level
Q_{Low} = the flowrate at low level
The numerical value of the TD ratio is typically reported as a ratio, such as 2:1.

It is important to note that the denominator term is flowrate in low level, and not low-low level. This is important as it is the differentiator between the concept of TD ratio and rangeability, which is discussed later. Generally, flowrate in low level (as shown in Figure 2) is considered to be the minimum level of flow at which the process goals can still be reached.

However, there is another interpretation of TD ratio that is often used

TABLE 1. TURNDOWN RATIO OF SELECT EQUIPMENT

Item	Turndown ratio
Pipe	Large, but depends on the definition of maximum and minimum flow
Storage containers (Tank or vessels)	Very large; The maximum value is the total volume of the container, but the minimum value could be dictated by a downstream component. For example, a centrifugal pump may dictate a minimum volume to provide required NPSH
Centrifugal pump	Typically: 3:1 to 5:1
Positive-displ. pump	Theoretically infinite
Heat exchanger	Small, depends on the type; for instance, less than 1.5:1
Burner [*1*]	Depends on the type; for example: Pressure jet type: ≈ 2:1 Twin fluid-atomizing type: >8:1

TABLE 2. UTILITY SURGE CONTAINER TO PROVIDE TD RATIO

	Surge container	Residence time
Instrument air (IA)	Air receiver	5–10 min. or higher depending on whether it is connected to UA or not
Utility water (UW)	Water tank	Several hours
Utility steam (US)	Utility steam cannot be stored for a long time without condensing; the options for storing steam are the steam drum of a boiler, or if a conventional boiler is not available, a vessel as an "external steam drum" could do the same task	
Utility air (UA)	No dedicated container; could "float" with IA	
Cooling water (CW)	Cooling tower basin	Depends on the size of the network
Cooling/heating glycol	Expansion drum	Depends on the size of the network

TABLE 3. TURNDOWN RATIO OF SELECT INSTRUMENTS

Item	Turndown ratio
Flowmeter: orifice-type	3:1 [*2*]
Flowmeter: vortex-type	10:1 to 50:1 [*2*]
Flowmeter: Coriolis-type	5:1 to 25:1 [*2*]
Control valve	Depends on type and characteristics; generally 50:1, and less than 100:1

TABLE 4. ARBITRARY VALUES OF FLEXIBILITY PARAMETERS

	Low flexibility	Medium flexibility	High flexibility
Equipment (TD ratio)	< 1.2:1 to 2:1	2:1 to 3:1	5:1 to 8:1
Instrument, control valves (rangeability)	≈ 4:1	10:1 to 30:1	20:1 to 100:1

by operations staff. During operation, people expect the TD ratio to answer the question in this scenario: "My plant is running normally and all parameters are normal. However, occasionally, because of different reasons (including shortage of feed, reduced plant or unit capacity), the flowrate falls. What is the minimum value I can withstand without compromising the quality of the product?"

They basically interpret the TD ratio so that the numerator is the "normal level parameter" (and not the "high level parameter"). However, the difference in the interpretation does not generate a big difference in numerical value of TD ratio, as the normal and high level of parameters are often not very far from each other. Due to this potential confusion, the TD ratio should be considered an approximate parameter and not a precise number. In general, the academic definition of TD ratio generally uses a high-to-low values set up, while in the field, operators often define TD ratio using normal-to-low values.

The TD ratio can be defined for parameters other than flowrate, but it generally refers to flowrate. One reason for this is because flowrate can be the most important parameter of a plant, helping to define the economy of the system. The other reason is because the flowrate might be influenced by constraints outside of the plant (for instance, a lack of stored feed), which the control system cannot necessarily adjust (thus making a reduction in flowrate unavoidable).

While the TD ratio is not always a requested parameter, and is often not mentioned in project documents for design purposes, operators are usually looking for a TD ratio of least 2:1 for a plant. The required TD ratio could be as high as 3:1 or 4:1 for a plant.

Equipment flexibility

The TD ratio can also be determined for a given piece of equipment, using other values that are stated for the component. For example, even when a TD ratio is not explicitly stated for a centrifugal pump, when the pump is said to have a capacity of 100 m^3/h and a minimum flow of 30 m^3/h, this means that the centrifugal pump has a TD ratio of 3:1.

The TD ratio of a reciprocating pump could theoretically be defined as infinite because it can work over a very wide range of flows. However, in practice, such a pump cannot handle any flowrate that fails to fill the cylinder of the pump in one stroke. Partial filling of the cylinder may cause some damage to mechanical components of the pump over the long term. Thus the minimum required flow is a function of cylinder volume and stroke speed of a specific pump.

The TD ratio for pipelines presents a more complicated situation. With piping systems, there are several different ways to define the minimum flow. For instance, it could be defined as the minimum flow that does not fall into the laminar flow regime. Or, it could be considered as the minimum flow that keeps a check valve open (if a check valve is used).

For liquid flows in pipes, the minimum flow is more commonly interpreted as the minimum flow that makes the pipe full, or the sealing flowrate (that is, no partial flow), or a flow threshold below which the fluid will freeze in an outdoor pipe. If the flow bears suspended solids, the minimum flowrate could be defined as that at which sedimentation of suspended solids may occur.

Table 1 provides examples of typical values and rules of thumb regarding the TD ratio for various types of process equipment. Note that in Table 1, the TD ratio of storage containers is relatively large. This high TD helps to explain why large containers are used for surge dampening as part of a typical plant-wide control system.

In some cases deciding on a required TD ratio needs good judgment. One example is chemical-injection packages. The TD ratio

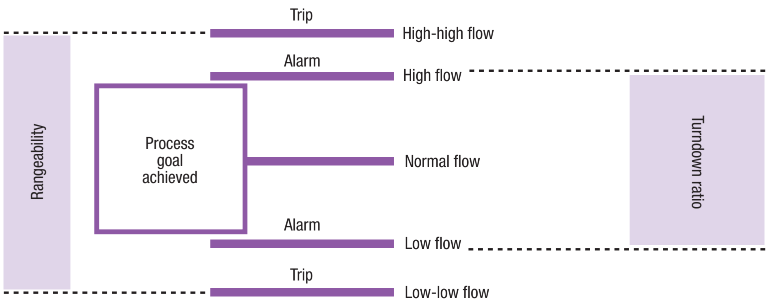

FIGURE 2. Process plants typically define different threshold values for flowrate levels, and set appropriate alarms and trips when the threshold values of this important parameter are reached. The concept of turndown ratio and rangeability are shown, in relation to these key threshold flowrate values

is important for chemical-injection packages to protect against chemical overdosing or underdosing.

Chemical-injection packages typically provide a TD ratio of about 100:1 or lower. In some cases, 10:1 can be provided by stroke adjustment, and another 10:1 through the use of a variable frequency drive (VFD) to control the motor. But the question that arises is why such a large TD ratio is necessary if the host flow experiences, for example, only a 2:1 TD ratio. This high TD ratio is generally desired because of uncertainty in the required chemical dosage and the variety of available chemicals. The required dosage of a chemical depends on the type of chemical and the host stream properties.

Thus, during the design phase of a project, the designer doesn't exactly know what the optimum dosage would be, even though a chemical provider recommends a specific dosage. Often, he or she prefers to conservatively have a chemical-injection system with a high TD ratio.

There is generally less uncertainty when using chemicals of known composition, rather than proprietary mixtures. If the dosage is fairly firm and the chemical used is a non-proprietary type, the TD ratio could be decreased, to reduce the overall cost of the chemical-injection system.

Utility network flexibility

The flexibility of a utility network is also defined by the TD ratio. As mentioned above, when a plant requires a TD ratio of, say, 2:1, the TD ratio of the utility network should be higher.

To accommodate a larger TD ratio, the utility network generally requires containers to absorb fluctuations that may be caused by utility usage changes in process areas. Table 2 provides additional details to support this concept.

Different segments of a utility network experience different levels of turndown, and consequently each segment may need a different TD ratio. For instance, as shown in Figure 3, the main header could need the minimum TD ratio, while sub-headers may need a higher TD ratio.

The good news is that achieving a high TD ratio for the utility network and related instruments is not difficult. The overall utility network is mainly a series of pipe circuits that inherently show a large TD ratio. If instruments are included in the utility network, this poses no problem. Many instruments (including control valves and sensors) have an intrinsically large TD ratio — generally greater than 20:1.

Instrument rangeability

Instruments typically need to operate over a wider range of process conditions than other equipment or utilities. This is because their duty is not limited to normal operation, or a band defined by low and high values. Rather, they have to be operational across the entire, wider band from low-low to high-high threshold values. Therefore, rangeability, R, can be defined as:

$$R = \frac{Q_{High-high}}{Q_{Low-low}} \qquad (2)$$

Where:

$Q_{High\text{-}high}$ = the flowrate of the instrument or control valve at the high-high level threshold value

$Q_{Low\text{-}low}$ = the flowrate at the low-low level threshold value

For control valves, the formula is a bit different because a control valve is a device that passes flow and also drops the pressure of the flow. Thus, the rangeability cannot be defined only as a function of flowrate — pressure drop also needs to be incorporated. The rangeability of control valves is a function of the control-valve flow coefficient (C_v).

Rangeability can also be defined for other parameters, such as temperature, but generally defining rangeability with regard to flowrate is the most important parameter. Table 3 shows some typical rangeability values for commonly used instruments.

It should be stressed that TD ratio and rangeability are two separate parameters, for two separate systems. They cannot be used interchangeably and attempts to relate or convert them to each other do not have much meaning.

Providing required flexibility

There are three main ways that one can provide a specific TD ratio for process equipment, and each is discussed below:

- Using equipment with an inherently high TD ratio
- Replacing equipment with multiple similar, smaller-capacity equipment in a parallel arrangement
- Providing a recirculation route

Using equipment with an inherently higher TD ratio. Some process elements have an inherently higher TD ratio. Two of them, tanks and pipes, were mentioned above.

It is not always easy to recognize if a piece of equipment has an inherently high or low TD ratio. However, the following rules of thumb can be used as guidelines:

- Smaller-volume equipment tends to have a smaller TD ratio than larger-volume equipment
- Equipment with internal baffles tends to have a lower TD ratio (a good example is some gravity separators, such as baffled skim tanks)
- Equipment in gas service may show a higher TD ratio than equipment used in liquid service
- Equipment with an internal weir (especially fixed ones) may have a very low TD ratio
- Equipment that uses some properties of the inlet stream for their functioning, may have a lower TD ratio. For example, in cyclones or hydrocyclones, the energy of the inlet stream ("energy" as a property of the inlet stream) is used to

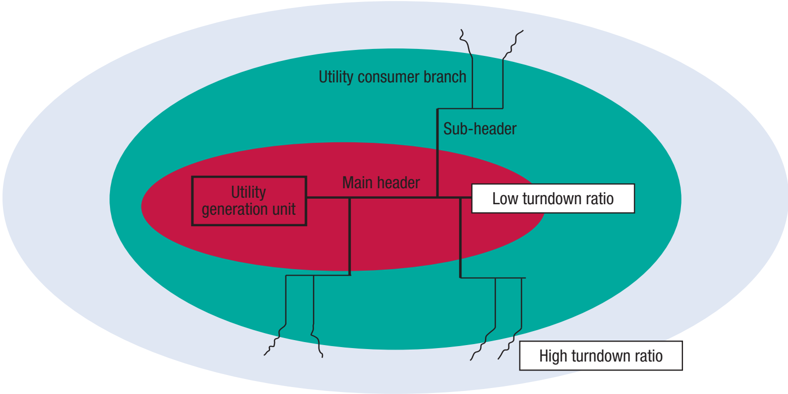

FIGURE 3. Shown here is a map of turndown ratio for a typical utility network.The pipes closer to the utility generation system (main header) need less turndown ratio compared to sub-headers and branches

generate centrifugal force, so any reduced flow will reduce the centrifugal force, which may reduce the effectiveness of the system

- Equipment containing loose, porous media may show a lower TD ratio in liquid service, and the TD ratio may be lower when the porous media is comprised of larger solid particle sizes. Examples include sand filtration systems, catalyst contactors and related systems
- Despite a common misconception, perforated-pipe flow distributors do not necessarily have limited TD ratios [*3*]

As noted, the utility network should have a relatively large TD ratio. Fortunately, utility networks consist mainly of pipes in different sizes, which have inherently large TD ratios. If control valves are needed on the network, their lower TD ratios may generate bottlenecks. In such situations, it may be necessary to install parallel control valves with split control, because of the required large TD ratio.

Using parallel equipment. Instead of using a component with a capacity of 100 m^3/h, this technique is essential to use an arrangement that employs two parallel components, each with the capacity of 50 m^3/h. By doing so, a TD ratio of at least 2:1 can often be provided. It should be noted that the equipment by itself may have some inherent TD-ratio capability, which may have to be added to the provided 2:1 TD ratio.

For example, instead of using one shell-and-tube heat exchanger with the capacity of 100 m^3/h, three heat exchangers — each with the capacity of 33 m^3/h —can be used to achieve a TD ratio of at least 3:1. The TD ratio may actually be higher because each shell-and-tube heat exchanger has an inherent TD ratio too, even though it is very small. This technique has additional benefits. The parallel arrangement provides higher availability for the system, because the failure of two or three parallel equipment components is less likely than the potential for failure when the system relies on a single equipment component.

Using two control valves in parallel in a single control loop (through a "split range" control) is also another example of this technique in the area of instrumentation.

However, there are some disadvantages associated with this technique. In particular, capital cost and operating cost considerations may rule against it.

Providing recirculation pipe. Implementing a recirculation pipe from the equipment outlet to its inlet is a widely used method to increase the TD ratio of the system. In many cases, a pump and definitely a control system, are needed to implement this technique. As long as you can afford an extra pump and control system on the recirculation pipe, this technique can be used. The recirculation pipe needs a control system, otherwise all flow goes through the recirculation pipe back to the inlet of the unit of interest (Figure 4).

One example of this technique is using a minimum-flow line for a centrifugal pump. A centrifugal pump with a capacity of 100 m^3/h and a minimum-flow line of 30 m^3/h (thus, with a TD ratio of 1:3) can be equipped with a minimum-flow line with an appropriate control system to increase its TD ratio. If the minimum-flow line and the control system are designed to handle a maximum flowrate of 30 m^3/h, it means the TD ratio of the pump can theoretically be increased to infinite, by zeroing the minimum flow.

Another example is a vertical falling-film evaporator. This type of evaporator has a vertical tube bundle that is similar to the ones found in a shell-and-tube heat exchanger. The tube-side flow is two-phase flow. The liquid flows down by gravity, and the vapor (of the same liquid) is pushed down by liquid drag. The flow inside the tubes is an "annular regime," meaning the liquid covers the internal perimeter of tubes and the vapor is in the center of the tubes.

In the case of low flow, there is a chance of "dry patches" forming on the tube's internal surface. Because of this, vertical, falling-film evaporators are typically equipped with recirculation pipes to provide a minimum practical TD ratio (Figure 5).

However, this method cannot be applied for all equipment. For example it is not a good technique to increase the TD ratio of a furnace or fired heater, because recirculation of fluid around a furnace may increase the furnace coil temperature and cause burning out if the firing system doesn't have sufficient TD ratio. Table 4 provides some rules of thumb to gauge the flexibiliy of different elements of a process plant.

Resistance against surge

While TD ratio refers to the static behavior of a plant, there are two additional parameters (resistance against surge, and speed of recovery from upset) that refer to its dynamic behavior. However, there is less emphasis on dynamic theories, and only practical aspects of dynamic behavior.

A process upset could result from a surge. Surge can arbitrarily be defined as the deviation of a parameter (such as flowrate) beyond its normal level. The final value of the parameter may or may not be in a band between high level and low level and the change often occurs quickly. When a parameter moves quickly, an upset could happen. The surge/upset could be defined for each parameter including flowrate, temperature, pressure and even composition. A surge in the composition is often called a slug. Level surge is generally

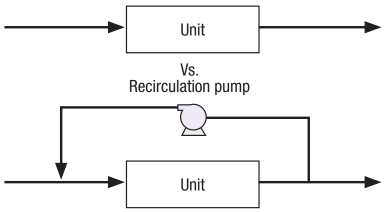

FIGURE 4. By providing a recirculation pipe, the turndown ratio of a piece of equipment can be increased. If the fluid pressure is not enough, a pump (or compressor) may be needed, and a control system is definitely needed

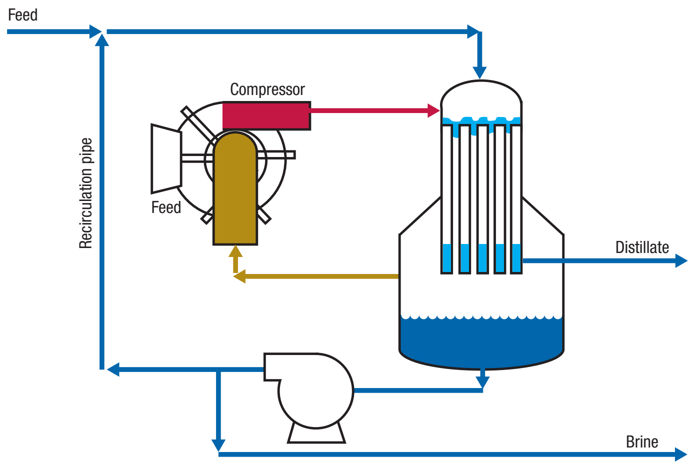

FIGURE 5. Shown here is a system for brine recirculation in a vertical falling-film evaporator. The brine-recirculation line in the vaporizer plays an important control role. Without the recirculation line, the vaporizer has a very narrow turndown ratio, which is not generally acceptable for optimal operation

a consequence of other surges and it can be dampened in surge-equalization tanks or drums.

Surge can also be defined by its shape (in a diagram of parameter change versus time), and by its magnitude. The magnitude of surge can be stated as a relative number or an absolute number. For example, a flow surge of 2% per minute is a relative number and means if a surge occurs in every minute, the flowrate is increased or decreased by 2%. In another example, a system can be said to be resistant to temperature surge (thus no upset conditions will be generated) as long as any potential surge remains less than 2°C per minute (an absolute value).

A 2%-per-minute surge means that the flowrate could start at 100 m^3/h and then increase to 102 m^3/h, then to 104 m^3/h and so on. Or the surge may start at 100 m^3/h and then decrease to 98 m^3/h, then 96 m^3/h and so on.

Some systems show different behavior against surge, when it is a positive surge (an increase in the parameter value), or a negative surge (a decrease in the parameter value). Therefore, it is good idea to clarify it. For example, an API separator could be more resistant to the impact of decreasing inlet stream compared to the impact of increasing the inlet stream.

The first line of defense against a surge is provided by the control system or control valves. However, control valves alone cannot totally eliminate a surge, but will only stop a surge from impacting a downstream system. Ultimately, the surge needs to be handled, but by other methods.

There are basically two surge-management methods that can be implemented for each piece of equipment or group of equipment in a plant:

- Boxing-in a surge in a specific equipment component or series of equipmen
- Transferring the surge to an external or auxiliary system

Understanding the applicability of each of these techniques requires some knowledge about the inherent dynamic characteristics of the systems from a process control viewpoint. The three dynamic features of each equipment or unit are resistance, capacitance and inertia (dead time) [*4*]. A brief qualitative explanation of these three features is presented next.

If a system is more dominantly a "resistance" type, this system will be able to prevent the surge from transferring to downstream equipment. A piece of pipe is one example of a resistance-type element. A pipe could inherently stop the surge if it is narrow enough. However, because a pipe's main function is to transfer fluid, the designer generally sizes the pipe based on its duty (transferring fluid) and then, if needed, a control valve is placed on the pipe to stop a potential surge.

The capability of a system to dampen the surge depends on the "capacitance characteristics" of the system. The higher the capacitance characteristic, the more it is able to dampen a surge.

Here, a capacitance-type element refers to whatever element that can be used to temporarily store excess mass (such as liquid volume or gas pressure) or energy (such as thermal or chemical energy).

For instance, large-volume equipment generally have a higher capacitance feature. Implementing a surge tank, equalization tank, surge drum (or even pond) is one means of providing a system with sufficient capacity to dampen the surge.

Another example of using a high-capacitance system is when transferring a surge to heat-exchange media. Utility heat exchangers use streams such as cooling water, steam, and other media, to transfer the heat to or from process streams. These utility streams are also able to absorb a temperature surge in the system. The capacitance feature of a utility network can be provided in part by pipes in the network (the pipes function mainly as resistance elements but they have some capacitance too), and also their surge tank, as discussed above.

A system is called robust against upset when it can tolerate a large surge (as defined for each process parameter) and no upset occurs, thereby allowing the process to proceed smoothly.

If an upset cannot be tolerated, one solution is to implement a rate-of-change control loop in the system. The following llist provides some general rules of thumb on the capability of a system to handle surges:

1. Generally speaking, equipment with larger volume

and fewer internals is better able to dampen upsets.
2. Containers with plug-flow regime are more susceptible to upset from surge compared to mixed-flow-regime containers.
3. The equipment that exerts centrifugal effect on the process fluid is more sensitive toward the upset (Examples include centrifuges and centrifugal pumps).
4. Containers that hold loose media are less robust against upsets.
5. Non-flooded containers can handle and dampen a surge better than flooded containers.

Speed of recovery from upset

The speed of recovery from an upset situation primarily depends on the dynamic characteristics of the system, and more specifically, the "process dead time" and "process time constant" of a system. The dead time is a result of inertia characteristics of the system, while the process time constant is a function of capacitance and resistance features of the system. A larger dead time or time constant means the system requires a longer time to recover from an upset.

However, in addition to this inherent characteristic of a system, other features can also impact (and decrease) the speed of recovery from an upset. Sometimes these features (rather than the dynamic behavior of the system) govern the behavior of the system. For example, a hot lime softener within a water-treatment system has an established sludge blanket. It takes time to "heal" a broken sludge blanket if an upset creates "breaks" in it.

Another example is "vessel-media" systems. These are systems that are used in operations such as ion exchangers, loose-media filtration systems, packing-type absorption towers, catalyst beds and so on. A big surge in flow may displace the media in a way that leads to flow channeling. Putting the displaced media back into a homogenous form takes time.

Similarly, a surge to a biological system will generally require a long recovery system, because a surge in temperature or slug of a toxic chemical may kill a large portion of the biomaterial growing there. ■

Edited by Suzanne Shelley

References

1. Mullinger, P., and Jenkins, B., "Industrial and Process Furnaces," 1st Ed., Amsterdam: Butterworth-Heinemann, 2008, p. 171.
2. Upp, E., and LaNasa, P., Fluid flow measurement," 2nd Ed., Gulf Professional Publishing, Boston, 2002, pp. 157–158.
3. Perry, R., Green, D. and Maloney, J., "Perry's Chemical Engineers' Handbook," 7th Ed., McGraw-Hill, New York, 1997, pp. 6–32.
4. Liptak, B., "Instrument Engineers Handbook — Vol 2. Process Measurements and Analysis," 4th Ed., CRC Press, Boca Raton, 2003. Chapter 2.

Author

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Organized by The Water Environment Federation (Alexandria, Va.; www.wef.org), this year's Weftec conference and exhibition is taking place Sept. 26–30 at McCormick Place in Chicago, Ill. Focusing on the water and wastewater industries, the event will feature a large exhibit hall, an extensive technical conference, interactive workshops and facility tours. This show preview covers a small selection of the products that will be displayed at Weftec's exhibit hall.

These self-cleaning filters are now available in a skid design

This company's Tequatic Plus F-75 and F-150 filters are now available in a new skid design, dubbed the B-Series Skid (photo). Tequatic Plus filters offer a self-cleaning solution for removing extremely high and variable solids content from fluid streams, even in the presence of fats, oils and grease. Operating where traditional filters may fail, the B-Series Skids reduce maintenance costs, and facilitate extended uptime. The technology is an appropriate choice in industrial wastewater treatment and reuse applications, including those handling water from food-and-beverage and oilfield processes. With the B-Series Skid, end users can decrease time requirements with "out of-the-box" installation and startup. Simple serviceability helps to further reduce labor costs, and quiet operation minimizes noise pollution. Booth 3791 — *Dow Water & Process Solutions, Edina, Minn.*
www.dowwaterandprocess.com

Double-containment piping systems help prevent failures

Poly-Flo co-extruded double-containment piping systems (photo), available in black polyethylene and Euro-grey polypropylene random copolymer, are suitable for installations with space constraints or systems where thermal expansion and contraction are present. Poly-Flo systems include full-pressure fittings, drainage fittings and machined fittings. The system is available in various sizes, and operates at pressures up to 150 psi at 68°F. Poly-Flo pipes and fittings act like a single-wall system, which helps prevent the types of failures often seen in fabricated systems. This is especially important in installations with fluctuating temperatures or applications like directional drilling, where opposing forces act on the carrier and containment pipes. The system's low cost and simple installation also make it suitable for drainage systems, pressurized transfer lines and industrial applications that require up to a 4-in. carrier pipe. Booth 4642 — *Asahi/America, Inc., Malden, Mass.*
www.asahi-america.com

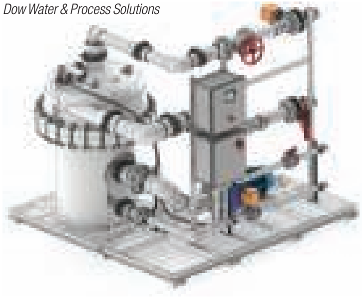
This system remotely monitors up to 12 process conditions

The Sentinel PRO remote monitoring system is an enhanced version of this company's Sentinel cloud-based system, which monitors up to 12 process conditions, including power, pump status, tank level and flowrate, from remote pump stations and tank farms. Sentinel PRO supports the Modbus communications protocol, and includes a second relay output, providing the capabilities required to integrate multiple devices and monitor complex networks. The Sentinel PRO system monitors process conditions, delivers alarms, and logs input-output points from third-party Modbus sensors, transducers and programmable logic controllers (PLCs). Alerts can be sent via telephone, email or text, and data values can be viewed in realtime via a Web-based portal or with dedicated smartphone applications. Booth 537 — *Sensaphone, Aston, Pa.*
www.sensaphone.com

Use these flowmeters in partially filled pipes

The Tidalflux 2300 (photo) is a new flowmeter designed for use with partially filled pipes. A Tidalflux meter can measure flows in pipes that are 10 to 100% full, and its non-contact sensor is not affected by the presence of oils and fats that may be floating on the fluid surface. In addition, Tidalflux flowmeters have a broad diameter range to fit pipes up to DN1600, or 64 in. The devices also boast high chemical and abrasion resistance to provide durability. Booth 3216 — *Krohne, Inc., Peabody, Mass.*
www.us.krohne.com

Dow Water & Process Solutions



Asahi/America

Krohne

Watson-Marlow Fluid Technology Group

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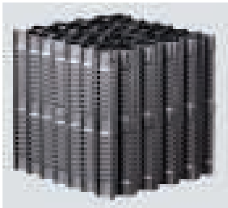


GEA Heat Exchangers

These pumps are updated with a maintenance-friendly design

The NEMO progressive-cavity pump line has been re-engineered with a maintenance-friendly, full service-in-place (FSIP) design, which provides full access to all of the pump's rotating parts. This allows users to open the pump cavity onsite and dismantle and re-install all rotating parts without having to remove the pump from the pipe assembly. The NEMO's rotor-stator unit can be simply lifted out after opening the pump housing's inspection cover. This significantly reduces installation and maintenance time. NEMO pumps are available in 11 styles, with four rotor-stator geometry options and a selection of engineered joints that can be tailored to suit specific water and wastewater applications. Booth 1461 — *Netzsch Group, Selb, Germany*

www.netzsch.com

These hose pumps can run at lower speeds, increasing hose life

The Bredel APEX range of seal-less, valve-less hose pumps (photo) are designed for dosing, metering and transfer duties at flowrates ranging from 0.012 to 27.3 gal/min, at pressures up to 116 psi, and are suitable for chemically aggressive or abrasive processing. The higher flow-per-revolution value means that APEX pumps can be run at lower speeds, increasing hose life and reducing wear. Recent international product trials demonstrated that the newest APEX models can extend the time between scheduled maintenance intervals when compared with air-operated diaphragm pumps and progressive cavity pumps, according to the manufacturer. Booth 4062 — *Watson-Marlow Fluid Technology Group (WMFTG), Cornwall, U.K.*

www.wmftg.com

Versatile polyethylene tanks that are potable-water certified

This company's line of corrosion- and chemical-resistant tanks and containers (photo), available in capacities up to 12,000 gal, are constructed from virgin high-density crosslinked or FDA-compliant linear polyethylene. Designed to store and transport corrosive and hazardous materials, these tanks provide low-temperature impact resistance, are ultraviolet-light stabilized and come in a wide range of capacities. Custom rotational molding and accessory fittings are available. The company's linear polyethylene tanks have received certification for NSF/ANSI Standard 61 for multiple potable-water contact materials up to 140°F. Booth 4078 — *Assmann Corp. of America, Garrett, Ind.*

www.assmann-usa.com

Peristaltic hose pumps capable of high discharge pressures

The Abaque line of peristaltic hose pumps is available in nine different models with flowrate capabilities ranging from 0.07 to 211 gal/min. Ductile-iron and steel construction enables the pumps to offer maximum discharge pressures as high as 15 bars. Abaque Series pumps feature a seal-less design that eliminates leaks and contamination. Hose options for the Abaque line include the following: natural rubber (NR), which is highly resilient with abrasion resistance and strength; nitrile Buna rubber (NBR), which is highly wear-resistant to oily products; and ethyl propylene diene monomer (EPDM), which features high chemical resistance, especially with concentrated acids, alcohols and ketones. Booth 4656 — *Neptune Chemical Pump Co., North Wales, Pa.*

www.neptune1.com

Polypropylene provides structural benefits for wastewater treatment

BIOdek polypropylene (PP) fill packs (photo) for wastewater treatment are lighter, more stable and more resistant to erosion than alternatives with the same thickness made of polyvinyl chloride (PVC), according to the manufacturer. The PP sheets are thermo-welded, with no need for the use of solvents in production, whereas PVC bonding requires potentially polluting chemicals. Disposal of used fill packs is straightforward, since PP emits no toxic substances when incinerated under controlled conditions. Due to PP's stability, strength and elasticity, trickling filters made of PP fills provide a surface that is robust enough for service staff to walk over without damaging the structure. Booth 2240 — *GEA Heat Exchangers, Bochum, Germany*

www.gea-hx.com ■

Mary Page Bailey

Water management

CHEMICAL ENGINEERING
ESSENTIALS FOR CPI PROFESSIONALS
Access Intelligence

special advertising section

PHOTO: FLEXICON

Water: a product, an ingredient, a utility

This Special Advertising Section celebrates a common – though increasingly valued – material on which every plant depends in one form or another

Inside:

Buss-SMS-Canzler
Carver Pump Company
Collins Instrument
Corzan Industrial Systems
Flexicon
FLEXIM GmbH
GEA Heat Exchangers
GEA Westfalia Separator
GEMÜ Valves North America
Hayward Flow Control
Industrial Cooling Tower Services
Inline Industries
MICRODYN-NADIR
Myron L Company
Orion Instruments
Ovivo
Ross, Charles & Son Company
SEEPEX
TEAM Industrial Services
Tuthill Vacuum and Blower Systems

A pure ingredient for $1–2/m.t. sounds like a bargain, yet that is the cost of water at many process plants. There can scarcely be a facility that does not take advantage of this versatile substance as a process ingredient, for cooling, for cleaning or for purification. For many plants, indeed, water *is* the product, and wastewater the raw material.

The equipment and technologies needed to deal with water in all its forms are diverse. Storing and moving water requires tanks, basins, pipes, pumps and valves. Purification involves a host of processes: biological and chemical treatment, ion exchange, and filter media ranging from sand to the finest reverse osmosis membranes. Analytical instruments, screens, centrifuges, blowers, and cooling towers all play their parts. Desalination is a huge topic on its own. The pages that follow feature a range of products and services to help engineers use water wisely and well. ■

PHOTO: CORZAN

In many facilities, water treatment takes up a significant area

A new twist in butterfly valve design

BYV Series butterfly valves from Hayward Flow Control feature advanced designs and materials to combine strength, corrosion resistance, and ease of operation

The revolutionary and patent-pending BYV Series Butterfly Valve from **Hayward Flow Control** incorporates the most advanced thermoplastic design and construction for butterfly valves in the industry today. Available in multiple thermoplastic materials from sizes 2 in. through 12 in. (DN50–300), the BYV Series has an extremely robust one-piece body construction while lighter weight than metal valves of equal size.

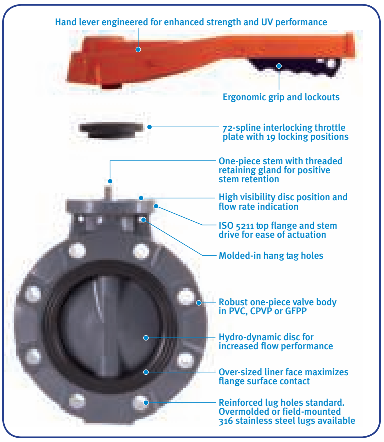
The revolutionary hand lever features a 72 spline interlock mechanism allowing for 19 stopping positions at every 5 degrees. The engineered hand lever material incorporates a UV inhibitor for enhanced performance in outdoor applications. The BYV also features reinforced lug holes, and can be ordered with overmolded 316 stainless steel lugs for dead end service or isolation needs. The BYV Series is available in ANSI 150 and DIN/EN PN10 flange patterns with a pressure rating of 150 psi (10 bar) at 70°F non-shock across all sizes and materials. Key features and benefits include:

- body and disc in PVC, CPVC and GFPP materials;
- EPDM, Viton or nitrile liners with oversized face;
- hydro-dynamic centric disc design for increased flow performance;
- one-piece 316 stainless steel stem with a threaded gland for positive stem retention;
- stem bearing and seal retainer for absolute stem positioning and sealing;
- ISO 5211 Top flange and stem drive;
- external disc position and flow indication;
- all sizes meet ANSI B16.10 / ISO 5752 narrow face-to-face dimensions.

Additional options include field-installable 316 stainless steel lugs, gear operators, pneumatic or electric actuators, manual limit switches, stem extensions, 2 in. square operating nut and chain operator for gearboxes.

BYV Series butterfly valves are made in Clemmons, NC, U.S., and backed by Hayward's exclusive two-year warranty.

Typical applications include chemical transfer and processing; waste and water treatment; aquatic and animal life support systems; mining; metal plating and surface finishing; marine; landfill and environmental infrastructure; and theme parks.



www.haywardflowcontrol.com

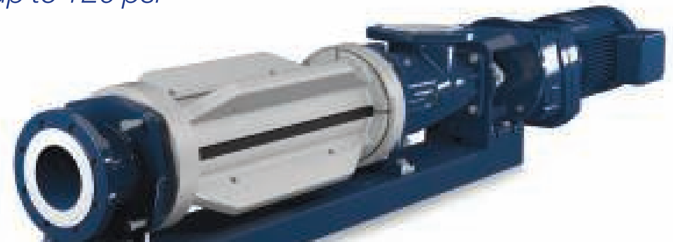
Pumps boast high pressures and easy maintenance

Continued innovation of SEEPEX progressive cavity pumps with Smart Conveying Technology now allows operating pressures up to 120 psi

SEEPEX introduced one-stage Smart Conveying Technology (SCT) to its progressive cavity pumps (PCPs) in 2008. Since then, thousands of these pumps have been successfully used in the chemical, environmental, pulp and paper, shipping, mining, pharmaceutical, and renewable energy industries, at pressures up to 60 psi. Now, two-stage SCT pumps handle the same applications and offer all the same benefits as one-stage SCT pumps, but have higher pressure capabilities: up to 120 psi. They utilize an improved adjustment mechanism to reach higher pressures. SCT PCPs can offer low life-cycle costs due to rotor and stator innovations that allow for reduced maintenance costs, prolonged stator life, and reduced energy consumption.

Conventional PCPs have a one-piece rotor connected to the power train by means of a universal joint. To remove or replace the rotor, the universal joint needs to be dismantled. SCT PCPs incorporate a smart rotor that is manufactured in two pieces: the rotor head and the rotor geometry. This allows the rotor geometry – the portion that wears – to be replaced without disrupting the universal joint, reducing replacement time and cost.

Conventional PCPs also have rubber stators chemically bonded inside a metal tube that creates a fixed compression between the rotor and stator. Typically, this requires the pump to be removed for maintenance. SCT PCPs, in contrast, do not need to be removed for maintenance, and the suction and discharge piping can remain in place. In both one- and two-stage SCT PCPs, the compression fit between the rotor and the stator can be adjusted to achieve the required pressures, reducing torque and operating requirements and costs. The SCT stator is manufactured in two pieces covered by four metal segments. These segments are held in place by adjusting mechanisms that can be easily removed to replace the stator halves. The segments can be tightened and readjusted to boost flow as a pump wears and volumetric efficiency decreases. When parts on an SCT PCP need replacing (usually after two or three stator readjustments), only the rubber stator pieces are discarded. Waste and the cost of disposal are reduced, impacting the overall carbon footprint and cost of pump ownership. **www.seepex.com**



SEEPEX progressive cavity pumps feature external adjustment of the fit between the rotor and the stator, for better performance and easier maintenance

Turn your phone into a portable water monitor

Combining portability, power and ease of use, pen-type measuring instruments from Myron L Company connect wirelessly to Apple devices

Myron L Company has released three UltraPen PTBTx Bluetooth-enabled Pocket Testers for use with Apple iOS 7 and iOS 8 mobile devices. These instruments are accurate, fast and simple to use in diverse water quality applications, the firm says. Features include automatic temperature compensation; highly stable microprocessor-based circuitry; user-intuitive design; and rugged, waterproof housing.

The PTBT1 measures conductivity, total dissolved solids, salinity, and temperature. Users may select from three solution types that model the characteristics of the most common types of water. The PTBT2 measures pH and temperature with 1-, 2-, and 3-point calibration options. The PTBT3 instrument measures ORP and temperature.

The PTBTx Pocket Testers replace the standard LCD display typical of most pen-type meters with large, easy-to-read characters via a free app that takes full advantage of the Apple iOS graphical user interface (GUI). Communication with the Apple device is via low-energy Bluetooth (BLE). Wireless operation makes it easy to move quickly from sample to sample, and allows the mobile device to be held safely away from the liquid samples being measured.

iOS devices provide large, clear displays for PTBTx portable water monitors

Each PTBTx can be given a unique user-programmable name, making it easily identifiable no matter what mobile device it is used with. Locations can be programmed into the app, either selected automatically via the Apple device's built-in GPS, or set manually for sampling sites that are too close together to be reliably distinguished via GPS.

Each measurement can be saved to the mobile device's memory. Saved records include measurement data, sensor settings, temperature, location, and the name of the PTBTx device used.

Records can be exported via the mobile device's e-mail function in various file formats: CSV, MS Excel, or Myron L Company's proprietary .mlc encrypted format.

Stored measurements are easily sorted, filtered, e-mailed, or deleted without affecting other records stored in the device's memory.

The PTBTx combine accurate measurement capabilities with the up-to-date GUI and computing power of a mobile device to provide a powerful tool for both field and laboratory applications. **www.myronl.com**

Traditional values with innovative pump designs

After 75 years Carver Pump Co. continues to supply pumps destined for some of the toughest industrial and military applications

Carver RS Series pump

Over three-quarters of a century, **Carver Pump Co.** has attained a reputation for creating value by providing pumps of premium quality with innovative designs for the automotive, chemical processing, mining, refining, power generation, general manufacturing and pulp/paper markets.

Boasting a product line known for its rugged construction features, a variety of horizontal and vertical end-suction pumps for multistage, axial split-case self-priming and API applications units are suitable for land-based, mobile and shipboard installations. With traditional values utilized in all phases of the operation to produce units of premium quality, new and innovative designs are routinely being developed to insure optimum performance.

Specifically designed for applications that require moderate to high discharge pressures, Carver has engineered a horizontal ring-section multi-stage pump known as the RS Series.

The RS Series is available in five sizes for flows ranging up to 1,400 GPM and pressures up to 1,500 psi. Featuring a product-lubricated radial sleeve bearing as standard and two matched angular contact bearings to handle the thrust, a low-pressure suction-side mechanical seal suits most requirements. Depending on the installation or application, these units are also available in a dual bearing/seal arrangement as an alternative design using ball bearings for both radial and thrust loads, plus a balanced mechanical seal for the discharge end.

Carver RS Series pumps are ideally suited for industrial and process applications including pressure boost systems, boiler feed, reverse osmosis, desalination and mine dewatering. **www.carverpump.com**

Traveling screens keep debris out of cooling systems

To protect pumps and heat exchangers downstream of cooling towers, traveling screens do a better job than traditional fixed screens, says Industrial Cooling Tower Services

Cooling tower sump screens are intended to protect circulation pumps and downstream heat exchangers from fouling and blockage. Unfortunately, says **Industrial Cooling Tower Services**, traditional fixed screens perform this important task rather badly. As a result, pump failures and heat exchanger efficiency losses due to debris continue to pose big maintenance challenges.

The problem lies in the periodic cleaning that fixed screens require, and specifically the action of lifting the vertical screen out of the sump pit. This stirs up debris lying on the bottom of the sump pit, while the absence of a pressure drop below the screen as it is being lifted creates an undertow that pulls debris off the front face of the screen.

In the case of a single fixed-grate screens, this loose debris moves directly into the suction pit. With a double screen, debris released by cleaning the first screen will be trapped by the second screen – only to be released again when the second screen is lifted.

According to the company, the solution is a traveling screen that moves in a vertical plane around two sets of rollers: one at the bottom of the sump pit and the other above the waterline. As the dirty screen moves up and over the top roller, a spray header backwashes debris into a collection tray.

The Vari-Flow SS Series Traveling Sump Screen is designed for simplicity and toughness to withstand the challenging environment of a cooling tower sump. It is rotated either manually or electrically, depending on size and process requirements. Typical mesh size is 0.375 in. Construction is in corrosion-resistant stainless steel, plastics and composites.

Since cooling tower sump screens do not conform to standard size guidelines, each Vari-Flow SS Series Traveling Sump Screen is custom-designed for the application it serves.

Most facilities view cooling water pump failures and heat exchanger fouling as largely inevitable, says Industrial Cooling Tower Services, and fail to investigate the root causes. With many problems due to inadvertent release of debris from fixed screens, a traveling screen is often a better alternative. **www.ictsinc.com**

Traveling screens avoid the problems associated with cleaning fixed screens

Decanter cuts energy consumption by up to half

*The GEA **water**Master delivers first-class results in the dewatering and concentration of sewage sludge, treatment of drinking water and recovery of valuable materials*

Highest reliability, maximum separation efficiency round the clock, and minimal energy consumption – the outstanding efficiency and productivity of the **GEA water**Master decanter are based on the following technical features.

GEA **eco**drive: The decanter has just one frequency converter, which supplies the primary motor when the machine starts up. Once the decanter bowl reaches its rated speed, the primary motor switches to direct mains power and the frequency converter supplies the secondary motor, where it controls the differential speed. This cuts energy consumption by 5% compared to other decanters.

GEA **summation**drive: The “intelligent kinematics” of the **summation**drive bring together the outputs of both motors and transmit them precisely to bowl and scroll. Unnecessary conversion losses, such as those which occur in other solutions involving reverse power (backdrive or additional belts), are not an issue. Instead, differential speed is supplied energy-efficiently and seamlessly across a broad range, saving up to 5% energy compared to other drives.

Deep pond design: The deep-pond design ensures optimized flow characteristics in the bowl, with high hydrostatic pressure, improved clarification, and less energy required to discharge the product. This reduces electricity consumption by up to 30% and also dramatically cuts the requirement for flocculents.

GEA **energy**jets: Using **energy**jets – specially-shaped weir plates with integrated flow deflection – allows the decanter’s energy requirement to be reduced by up to a further 10%.

The waterMaster combines several energy-saving features

The specific energy consumption of the **water**Master has thus been reduced by up to 50% overall. GEA has also managed to reduce flocculent consumption, rendering water and wastewater treatment more sustainable and ensuring that investments holds their value for longer. This is especially important in times of rising disposal costs and energy prices. **www.gea.com**

Plastic control valves handle corrosive chemicals

Collins 2-in. valves and actuators are specially designed to handle corrosive fluids – acids, bleaches, chlorine, pH control – and aggressive environments

Collins Instrument Company’s line of economical 2-in. flanged plastic control valves handle corrosive liquids including hydrochloric acid, caustic, sulfuric acid, and many others. With bodies of either PVDF or polypropylene, these highly-responsive control valves are specifically designed for use with corrosive media and/or corrosive atmospheres.

Suitable for applications in numerous industries, including chemical, petrochemical, pulp and paper, and municipal, these valves are extremely corrosion-resistant, and feature fast-acting positioning (stroke rate approximately ½ in./s). They are available with a wide selection of trim sizes, in globe, angle, and corner configurations.

The differential-area piston eliminates the necessity for auxiliary loading regulators. All actuator parts apart from the integral positioner are molded of glass-filled, UV-inhibited polypropylene. Before shipment, the aluminum positioner and a portion of the cylinder are immersed in Dip Seal to provide atmospheric protection.

Plastic valves and actuators from Collins

The integral positioner eliminates the need for external linkages which are subject to corrosion and malfunctioning. Valves may also be furnished without a positioner for on/off applications.

Collins also offers a plastic pneumatic actuator. The combination of a plastic actuator and a plastic valve body provides an effective way to handle both corrosive materials flowing through the valve, and harsh environments that can attack the outside of the valve and actuator. Collins plastic control valve packages withstand salty marine atmospheres as well as industrial environments that are too corrosive for metal valves and actuators.

Collins actuators incorporate a unique internal locking ring to attach the cylinder to the yoke. A semicircular groove is machined inside the lower edge of the cylinder, and a matching groove cut in the yoke. When the yoke and cylinder are assembled, a flexible polypropylene rod is inserted into the groove through a slot in the side of the cylinder, securing the two sections together.

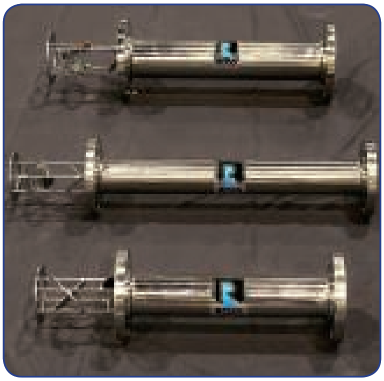
Along with its corrosion resistance the Collins control valve features a stem packing arrangement that virtually eliminates the problem of fugitive emissions, thereby protecting the environment.

Located on the Texas Gulf Coast in the town of Angleton, Collins Instrument Company has been serving the chemical and petrochemical industry for over 65 years. **www.collinsinst.com**

Static mixers with low pressure drop

Ross LPD Low Pressure Drop Static Mixers are ideal for effective fluid mixing in water and wastewater treatment processes

The **Ross** Low Pressure Drop (LPD) Static Mixer enables more efficient dosing of flocculants, disinfectants, neutralizing agents and pH conditioners into a water stream. This simple-to-install heavy-duty device completely mixes treatment chemicals within a short length of pipe. When used in conjunction with automated instrumentation, the LPD delivers predictable quality control based on a virtually maintenance-free operation.



Four or six mixing elements are usually more than sufficient for effective mixing under turbulent flow conditions, Ross says. Diameters range from 1 in. through 48 in.

The LPD Static Mixer consists of a series of baffles or "elements" discriminately positioned in series. Each element comprises a pair of semi-elliptical plates set 90 degrees to each other. The next element is rotated 90 degrees about the central axis with respect to the previous baffle set, and so on. For even lower pressure drop, an LLPD model is also available, in which the plates of each element are oriented at 120 degrees relative to each other.

As the fluid moves through each LPD or LLPD element, flow is continuously split into layers and rotated in alternating clockwise and counterclockwise directions. This method of subdividing the stream and generating striations leads to highly efficient and repeatable mixing with minimal pressure loss. During turbulent flow, the baffles enhance the random motion of molecules and the formation of eddies. In most water and wastewater processes, four or six elements are more than sufficient to completely disperse treatment chemicals and create a very uniform solution or suspension.

Small LPD/LLPD mixers of 1 in. through 2.5 in. in diameter are welded to a central rod, while larger elements are welded to four outside support rods for maximum rigidity and stability. Available in a wide range of sizes up to 48 in. in diameter, these mixers can be supplied as pipe inserts or as complete modules with housing and injection ports.

In addition to Static Mixers, Ross also manufactures High Shear Mixers and Multi-Shaft Mixers used in the production of water treatment chemicals. The company offers no-charge mixer testing services and an extensive trial/rental program.

www.mixers.com

Valves for water treatment plants

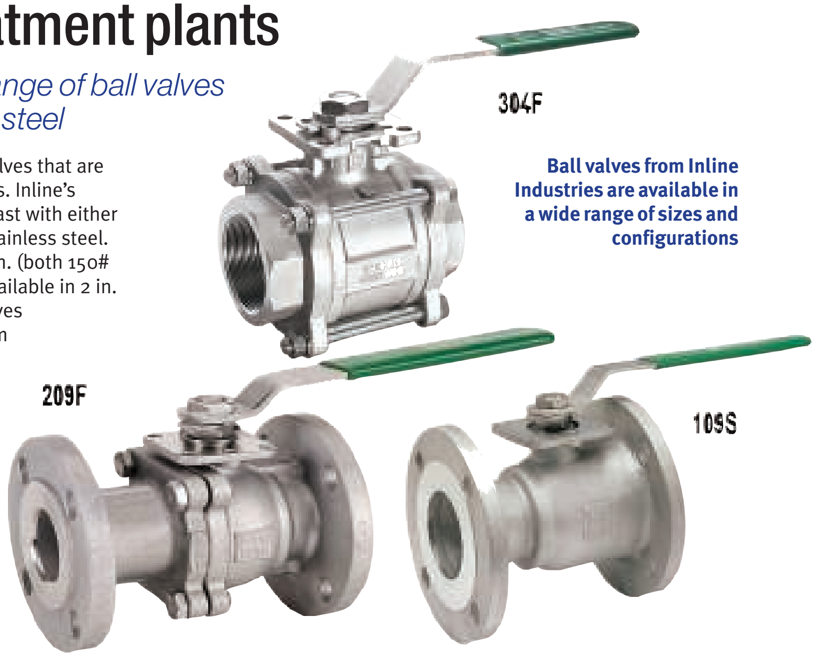
Inline Industries supplies a wide range of ball valves in both stainless steel and carbon steel

Inline Industries offers flanged and three-piece valves that are well suited for waste and water treatment facilities. Inline's one- and two-piece flanged valves are investment cast with either WCB carbon steel or 316 (AS Grade A351 – CF8M) stainless steel. Flanged full-port valves are available in ½ in. to 12 in. (both 150# and 300#). Flanged standard-port ball valves are available in 2 in. to 6 in. (150#). Inline's three-piece, full-port ball valves come in 316 stainless steel or WCB carbon steel from ¼ in. to 4 in. Inline also carries three-piece valves in CW12MW, a highly corrosion resistant material ideal for chemical feed applications.

Inline offers diverter valves in either a 3-way configuration for simple diverting applications, or true multi-port valves for diverting applications with shut-off positions.

Inline has a complete automation facility on site and can provide pneumatic or electric actuation packages for various air pressures and voltages. Accessories, from simple line-of-sight position indicators to complete digital feedback systems, are available. All packages are assembled in-house and tested before shipping to the plant site. Special cleaning requirements, if needed, can be provided.

Inline maintains a vast inventory of valves, replacement parts and seal kits. With most orders shipping within 24 hours, customers are often able to reduce their backup inventory requirements.



Ball valves from Inline Industries are available in a wide range of sizes and configurations

www.ballvalve.com

Economical thin-film sludge drying

Buss-SMS-Canzler offers drying solutions for municipal and industrial wastewater treatment sludge

Municipal sludge is increasingly regarded as a valuable product, as the direct use of sludge as a fertilizer faces future restrictions. Industrial sludges, on the other hand, have to be incinerated in most cases. The pre-drying or full drying of sludges from both municipal and industrial wastewater treatment plants is therefore often a mandatory step, says **Buss-SMS-Canzler**.

Pre-drying is normally carried out to one of two moisture levels:

- 35–50% dry solids prior to incineration in fluidized-bed incinerators; or
- 65–75% dry solids prior to composting or co-incineration with garbage.

Full drying, to 85–95% dry solids, is typically needed:

- for use as a fuel for cement kilns or coal-fired power stations, or for pyrolysis, gasification or other conversion routes; and
- before sludge is used for composting, agriculture or soil reclamation.

These are typical applications in which the thin-film drying process can show its advantages where evaporation rates of

A thin-film dryer from Buss-SMS-Canzler destined for sludge drying

0.2–8 m.t./h of water are required. The thin-film dryer is characterized by:

- single-pass operation through the sticky or pasty phase, without the need for back-mixing of dried product;
- low energy consumption;
- self-cleaning heat exchange surface;
- self-inerting thanks to the presence of evaporated water; and
- low operating and maintenance costs.

www.sms-vt.com

Clamp-on flowmeter is SIL2-certified

Where functional safety is important, FLEXIM flowmeters offer IEC 61508 compliance as well as high accuracy

FLEXIM clamp-on ultrasonic flowmeters combine accuracy with ease of use

The world's first ultrasonic clamp-on flowmeters, the FLUXUS series from **FLEXIM**, are suitable for process control applications meeting the functional safety requirements of IEC 61508. They are certified as SIL 2-capable, and available in versions for potentially explosive atmospheres.

The FLUXUS F/G70X and F/G80X series are designed for permanent, non-invasive flow measurement of liquids and gases. The transducers are simply attached to the outside of the pipe, without interrupting the process, and are virtually maintenance-free because no part of the flowmeter is in contact with the process medium.

Measurements using the ultrasonic transit-time principle offer high accuracy and an extremely high dynamic range, for flow in either direction. The available flow transducers cover a nominal pipe size range of 6 mm–6.5 m.

Used with the patented WaveInjector transducer mount, FLUXUS meters can measure at pipe wall temperatures from –170°C to 600°C. Thanks to carefully matched transducer pairs, unique internal temperature compensation and sophisticated internal signal processing, they are highly stable in terms of zero-point and drift. To maintain flexibility in installation, FLEXIM calibrates transducer pairs and transmitters independently of each other. **www.flexim.com**

New membrane bioreactors

MICRODYN-NADIR modules are available for large plants

Since 2005 **MICRODYN-NADIR**, the membrane and module manufacturer from Wiesbaden, has offered the only membrane bioreactor (MBR) product that combines the advantages of hollow fibers and plate-and-frame modules whilst avoiding their particular disadvantages – the BIO-CEL. Up until 2014 BIO-CEL modules were available with membrane areas of 10, 50, 100 and 416 m^2.

Increasing acceptance of MBR technology has now resulted in more large projects with inflows above 10,000 m^3/d. To address these demands MICRODYN-NADIR has developed the BIO-CEL XL module especially for large-scale applications with wastewater flows above 2,000 m^3/d.

The new BIO-CEL XL module provides a total membrane area of 1,920 m^2

The BIO-CEL XL module has a total membrane area of 1,920 m^2. The greatly increased membrane area is not the only benefit; more importantly, this large membrane area is mounted in a comparably small stainless steel housing with a very compact footprint (length: 2786 mm × width: 2106 mm × height: 2450 mm). This results in extremely space-saving installations.

Another important benefit is a reduction in the effort required for piping. The BIO-CEL XL requires only one connection pipe to the blower and one permeate pipe.

Operation of the BIO-CEL XL matches that of the smaller types of BIO-CEL module, which have many years of proven success. Successful operating experience with the BIO-CEL XL in a municipal wastewater treatment plant has been available since August 2013. **www.microdyn-nadir.de**

Blower packages for wastewater treatment

Tuthill Vacuum & Blower Systems offers solutions for treating wastewater in chemical processing applications

Chemical and pharmaceutical manufacturing facilities produce a wide variety of products that can produce wastewater as a by-product of their industrial process. Many facilities have on-site wastewater treatment plants to treat the water to be recycled back into their processes or to process it before introducing it to a municipal system.

Blower packages are often used in these applications especially in noise-sensitive areas. **Tuthill Vacuum & Blower Systems** manufacturers the Qube Blower Package that is sold into this market. The Qube is designed with a maintenance-friendly enclosure and a compact footprint. There are three models available, offering flow ranges of 41–400 CFM, 159–800 CFM and 431–1600 CFM respectively. These models deliver pressures up to 18 psig and vacuum up to 17 in. Hg.

Tuthill's Qube Blower Package is built with one of the company's most reliable, best-performing blowers. The package design has a shaft-driven cooling fan that does not require additional electrical service. There is an oil drain/level gauge accessible from the front of the package for easy oil change. The mounting base includes integral fork truck pockets for easy transportation and on-site positioning.

Additional features include: external oil sight gauge, automatic belt tensioning system with visual indicator, vibration isolators, relief valve, pressure gauge, filter restriction gauge, inlet filter, oil filter reservoir, and vent fan. There are also a variety of optional accessories and controls available to best meet customers' needs.

Tuthill designs and manufactures the Qube Blower Package in Springfield, Miss., U.S. When custom systems are required, Tuthill has a Systems Engineering Group ready to assist. The team will manage a customer's project from start to finish with all design and manufacturing completed in Springfield. **tuthillvacuumblower.com**

Tuthill's Qube Blower Package is targeted at wastewater treatment. Available in three sizes, it is highly customizable and designed for easy maintenance.

An alternative source for cooling water

As process water becomes an increasingly precious resource in many areas, Ovivo shows how to use reclaimed water for cooling tower make-up and even boiler feed

For centuries, water was considered a commodity product and used with little or no restriction, notes water technology specialist **Ovivo**. In today's modern society, however, water is now considered a precious resource, with considerable effort put into protecting and recycling it. U.S. State and Federal agencies have put in place guidelines and regulations restricting water use, especially by industry, such as EPA 316(b) environmental guidelines to protect aquatic life and endangered species.

As the use of fresh water or seawater for cooling tower make-up water becomes restricted or unavailable, other water sources need to be considered. One potential alternative for cooling is the use of treated municipal wastewater. According to the Energy Information Administration (EIA), 81% of newly proposed power plants could get enough cooling water from one or two wastewater treatment plants within a 10-mile radius. Going even further, with the correct post-treatment, water from municipal treatment plants is even suitable for use as boiler feed water (BFW) makeup.

Softening with lime, shown here, is one of many treatment options offered by Ovivo

Reclaimed water brings a number of challenges. High levels of nutrients can sustain the growth of living organisms that cause bio-fouling within cooling systems. Phosphorus, ammonia/nitrogen and other dissolved salts, meanwhile, contribute to scaling and corrosion of equipment. Additionally, the presence of pathogens and other toxins in the water may require further treatment of the water before it is used, and of the blowdown afterwards.

Ovivo, with more than 200 years of experience in water and wastewater treatment, can help in selecting the most economical and efficient water treatment technologies available, including:

- screening and filtration via coarse screens, multimedia filters or membrane technologies (micro- and ultrafiltration);
- sedimentation via clarifiers or dissolved gas flotation;
- softening using lime or alum;
- purification via membrane technologies such as MBR, RO, ion exchange, and EDI;
- treatment for bacteria, odor etc. using activated carbon and UV light;
- separation management and removal of solid waste and sludge using press filters, belt filters, and sludge compactors;
- chemical dosing and pH control;
- mechanical cleaning of condenser and heat exchanger tubes with recirculating rubber balls or brush-and-basket cleaning systems. **www.ovivowater.com**

Bulk bag unloading system contains toxic fluoride dust

ProMinent Fluid Controls uses solids handling equipment from Flexicon for drinking water fluoridation systems in Australia

ProMinent Fluid Controls Pty Ltd. of Australia has supplied more than 60 fluoridation systems over the past 25 years to water treatment plants that output 33–200 million gal/d, says Neville McKee, a ProMinent sales manager.

ProMinent designed a fully automated process in which sodium fluorosilicate (Na_2SiF_6) is completely contained in a sealed transfer system at all times.

The major pieces of equipment are the bulk bag discharger, a dust containment system, and the flexible screw conveyor, all supplied by **Flexicon Corp. (Australia) Pty Ltd.** of Brisbane.

Bulk bags of 2,200 lb are lifted into place on the discharger frame by an electric hoist and trolley on a cantilevered I-beam.

Powder is discharged from the bag into the transition hopper through a double-wall Tele-Tube telescoping tube. The tube is secured to the bag spout by a patented Spout-Lock clamp ring that creates a dust-tight seal. Continuous downward pressure on the spout helps maintain a steady flow.

A pneumatic Power Cincher flow control valve allows gradual release of material from the bag, and can cinch a partially empty bag.

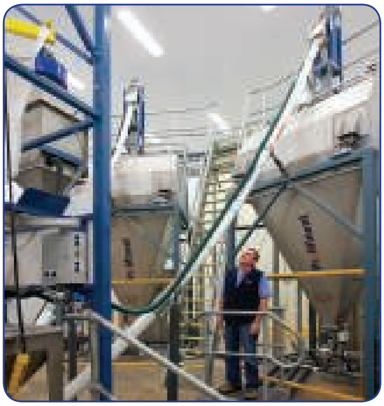
Promoting flow are Flow-Flexer bag activators – pneumatically driven plates that raise and lower opposing bottom edges of the bag to direct material to the outlet.

The dust-tight system is vented to a Bag-Vac dust collector that collapses empty bags prior to tie-off, avoiding dust generated when empty bags are flattened manually.

A Flexicon conveyor transports Na_2SiF_6 from the floor hopper to a storage hopper that feeds the mixing tank.

Finally, the solution is metered into the flowing water supply by a peristaltic pump (or a progressive cavity standby pump).

The Flexicon system is the only one that ProMinent uses for fluoridation plants, says McKee. "We have only ever promoted Flexicon bulk bag unloaders with double-wall telescoping tubes for fluoride, as we found it to be the best available to handle a toxic powder with minimum risk of dust," he says. "I think it would be a brave water supply authority to try a different brand at the moment, as we have promoted this since the application arose for bigger bulk-type fluoride installations." **www.flexicon.com**



Two flexible screw conveyors feed fluoride powder from a bulk bag discharger into two seven-day storage hoppers

Precise dosing with multi-port fluoroplastic valves

For process reliability under stringent process requirements, GEMÜ offers multi-port valve blocks made from fluoroplastics

GEMÜ multi-port valve blocks provide precise dosing of ultra-pure water or chemicals, while withstanding heavy-duty switching cycles and providing long service life. The multi-port valve shown here is a plastic valve block from the iComLine series manufactured by GEMÜ, made from ultra-pure PVDF material and featuring innovative seat diaphragm technology with PTFE. This combination of materials allows for heavy-duty switching cycles and resists temperatures up to 150°C.

Plastic multi-port valve blocks combine multiple valve seats in one unit. This means that plants can now be built much more compactly because the pipe connections, fittings and even various sensor components can be integrated into a single unit. Through customized calculations and configurations of the regulating cones, it is possible to implement very specific control characteristics alongside simple open and close functions.

Thanks to a wealth of experience acquired over 20 years in the manufacturing of stainless steel multi-port valve blocks, and in handling critical media in the semiconductor and chemical industries, GEMÜ has now been able to successfully transfer this expertise to the field of high-performance thermoplastic block valves. With its modular system, GEMÜ can provide individually adapted solutions to meet specific customer requirements, and supplies everything from a single source.

Compact and efficient, this GEMÜ multi-port valve block is made from thermoplastic and fitted with valves from the iComLine series

GEMÜ is one of the world's leading manufacturers of valves, measurement and control systems. Since 1964, this globally focused, independent family-owned enterprise has established itself in important industrial sectors thanks to its innovative products and customized solutions for process media control.

Today GEMÜ has several manufacturing centers and a presence all over the world. The company is committed to the pursuit of quality and excellence in the development and manufacture of its products.

www.gemu.com
WEFTEC, Booth 5413

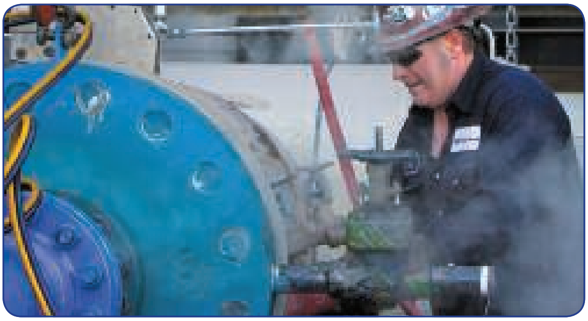
Minimizing downtime, maximizing performance

Team Industrial Services offers a wide range of specialized services that allow plant turnarounds to be conducted quickly, effectively, and above all safely

Turnarounds allow for necessary maintenance and upkeep of operating units and are needed to maintain safe and efficient operations. Founded in 1973, **Team Industrial Services** is the worldwide leader in minimizing equipment and asset downtime, providing a number of services to assist with turnarounds and outages including on-line maintenance, inspection and repair. The company provides critical services to its customers that enable them to maintain and operate their facilities and equipment in a safe and productive manner.

Team's line of specialized industrial services includes bolting/torquing, concrete repair, emissions control, exchanger services, field machining, fitness for service, heat treating, hot tap/line stop, isolation test plugs, leak repair, manufacturing/engineering, mechanical integrity, NDE/NDT inspection, project services, specialty welding, turnkey tank program, valve insertion, and valve repair.

Team employs only the best, most qualified technicians to ensure each and every job is completed to the highest standards every time. The company maintains management systems and documented work procedures designed to assure compliance with all applicable laws, regulations and internal requirements, as well as to facilitate the continuous improvement of its processes, products, and personnel. The highest priority at Team is the safety of employees, clients, and other contractors. The company is committed to safety excellence and strives daily for zero injuries and incidents.



Safe working methods are always a priority for Team personnel

Today, Team is rapidly growing its global footprint across a wide range of industries – with service locations in five continents. The company recognizes that its global success is ultimately measured by its customers' trust and confidence, which can only be earned through continuing outstanding service. Team's trained and certified technicians are available worldwide 24/7/365. From single part repair to turnarounds and shutdowns – planned or unplanned – Team has the training, experience, technology and know-how to deliver high-quality maintenance, inspection, and testing services anytime, anywhere. **www.TeamIndustrialServices.com**

Solving pipe corrosion in wastewater treatment

Corzan CVPC industrial piping systems are resistant to high pressures and temperatures, as well as solving problems related to corrosion and bacteria

Harsh environments associated with wastewater treatment can wreak havoc on traditional industrial piping systems. Severe weather, corrosive chemicals and bacterial growth can all affect the pipes' overall performance and reliability.

Through years of use and extensive testing, **Corzan** CPVC industrial piping systems have proven that they possess the chemical resistance and mechanical strength necessary to endure a wide array of environmental challenges. Corzan is corrosion-resistant and durable, with a smooth interior surface that resists bacterial growth.

Chemical resistance: By replacing traditional metal piping systems with Corzan, engineers can extend equipment service life and reduce maintenance, while minimizing process life-cycle costs. In general, Corzan is inert to most mineral acids, bases, salts, and aliphatic hydrocarbons, and compares favorably to other non-metals in these chemical environments.

Corzan outperforms PVC within industrial process applications

Weatherability: Corzan CPVC has been blended with a significant concentration of both carbon black and titanium dioxide (TiO_2), which are widely recognized as excellent ultraviolet blocking agents to protect the polymer backbone from the effects of ultraviolet radiation. As a result, Corzan piping systems maintain their pressure-bearing capability even after prolonged exposure to sunlight.

Impact resistance: Corzan CPVC has three times the impact strength of standard CPVC. Higher impact strength allows the pipe to be cut more easily on the construction site because there are fewer fractures, so the scrap rate is lower.

Microbiologically influenced corrosion: Corzan CPVC industrial piping systems are resistant to attacks from fungi and contain no additives that could provide a nutrient source for fungi.

Low friction: The smooth interior surface of Corzan helps the pipe resist the build-up of all forms of bacteria, many of which are known to cause corrosion in metal piping systems, such as iron-oxidizing bacteria, sulfate-reducing bacteria, and acid-producing bacteria. Corzan will not fail prematurely due to corrosion, electrolysis, or scale build-up in areas where water, soil or atmospheric conditions are aggressive.

Corzan industrial piping systems provide the ultimate in safety by meeting ASTM F441 classification. Corzan CPVC is field-proven to meet the ever-increasing demands of wastewater treatment operations.

www.corzan.com

Level monitoring for water management applications

Orion Instruments' magnetic level indicators out-perform ordinary sight glasses

From boilers to separators, from deionization to wastewater treatment, water management on any process plant involves a host of vessels and tanks that need to be monitored. Proper level monitoring and control is necessary for the safety and efficiency of nearly every liquid vessel application, points out **Orion Instruments**.

For many years, sight glasses were the dominant level measurement instrument because of their simplicity, but there are many issues inherent in this level technology. Leak points, cracking, low visibility, and high maintenance costs all must be contended with when using sight glass gauges to view liquid level. Fortunately, Orion Instruments offers a safer and more reliable solution with its custom-engineered line of magnetic level indicators (MLIs).

MLIs house process liquid within a rugged stainless steel chamber mounted externally to the vessel via a set of process connections. Within the chamber is a magnetic float designed for the conditions of each application and weighted to sit at the level of the liquid. As the liquid and float rise or fall, magnets in the float flip dual-colored magnetic flags mounted outside the chamber, which indicate the level. Since the flags do not come into contact with the process media, risk of contamination and clouding of the viewing window is essentially eliminated.

For harsh applications like wastewater treatment, Orion MLIs can be made from plastics like Kynar and PVC in place of stainless steel. By adding a second float, an MLI is able to measure both interface and total levels, which is useful for monitoring separators.

In some applications such as boiler control it is especially important to be able to adjust the liquid level in real time. By equipping them with electronic switches or transmitters, MLIs can become control instruments in addition to measurement devices. Guided-wave radar and magnetostrictive transmitters can supply a 4–20 mA, HART or Foundation Fieldbus output signal allowing for continuous level control. Orion's patented Aurora MLI combines magnetic visual indication with state-of-the-art guided-wave radar in a single chamber to provide truly redundant level measurement with a small footprint.

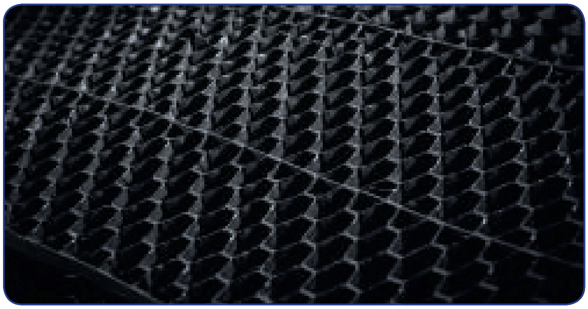
www.orioninstruments.com

Polypropylene fills for clean water around the world

Although GEA Heat Exchangers is changing its identity, its products remain the same

"Heat exchange is at the heart of what we do. We stand for the triad of people, machine, and our new brand identity," says **GEA Heat Exchangers**. During the transition to a new corporate presence the company is initially focusing on its decades-old core business and on its employees. Customers can be reassured that the products of the heat exchanger specialist, including polypropylene (PP) fills for biological water treatment plants, will not change.

The advantages of PP fills over alternatives made of PVC have been recognized throughout the world for the treatment of wastewater, the company says. 2H BIOdek PP fills are lighter, more dimensionally stable and more resistant to erosion than those made from PVC of the same thickness. They are also more environmentally friendly, starting with production. The PP sheets are thermo-welded, with no need for the volatile organic solvents required to bond PVC. Disposal of used fill packs is likewise unproblematic, since PP, as a pure hydrocarbon, emits no toxic substances such as dioxins or hydrochloric acid when incinerated under controlled conditions.



2H BIOdek polypropylene fills are stronger, lighter and more elastic than those made from PVC

PP is more elastic than PVC and resists loads better. Measurements on blocks of PP and PVC, each with a density of 35 kg/m^3 and a corrugation height of 19 mm, show that the PP block has a higher compressive strength and mean sheet thickness. The assembly technique for PP also contributes to its greater stability and robustness. PP welding techniques developed by GEA Heat Exchangers, which feature approximately 10,000 weld spots per m^3, assure permanent connections between the individual PP sheets.

Taken together, these properties mean that trickling filters made with PP fills provide a surface stable enough for service staff to walk on safely for maintenance purposes. A comparable PVC fill, on the other hand, requires a catwalk grating for maintenance, and is also heavier, less flexible, and thinner: all factors that increase the risk of structural collapse during operation.

Throughout the world, more and more facilities are counting on PP fill packs. Recently, for example, GEA Heat Exchangers received an order to equip a sewage treatment plant in Addis Ababa, Ethiopia, with 2H BIOdek fills made of PP. The facility will have a capacity to serve more than one million residents. This project for Kaliti, one of the sub-cities of Addis Ababa, has been financed by the World Bank and will supplement the existing wastewater ponds by adding a biological treatment stage. **www.brand-change.com**

Product Showcase

Vector® Process Pumps

Any Fluid or semi-solid

- Hot, chemical
- Viscous
- Bio-reactive
- Toxic
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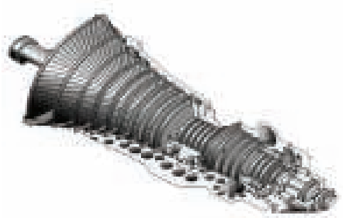
When a plugged drain line would mean disaster...



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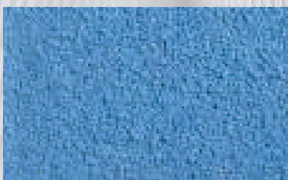

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Economic Indicators

2013 ▬ 2014 ▬ 2015 ▬

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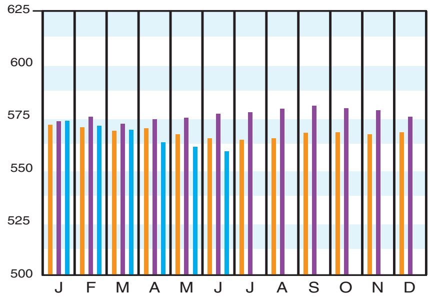
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Jun. '15 Prelim.	May '15 Final	Jun. '14 Final
CE Index	558.6	560.5	576.2
Equipment	673.1	675.6	700.1
Heat exchangers & tanks	601.8	603.5	638.0
Process machinery	659.6	658.7	673.8
Pipe, valves & fittings	836.3	843.6	880.3
Process instruments	398.9	402.6	410.8
Pumps & compressors	957.8	958.0	938.2
Electrical equipment	512.9	513.0	515.3
Structural supports & misc	737.7	740.1	770.0
Construction labor	321.4	322.7	319.8
Buildings	541.5	542.7	543.4
Engineering & supervision	319.8	319.5	320.6

Annual Index:
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1

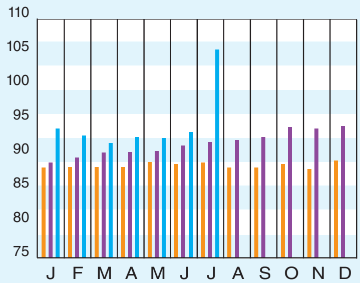


Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics

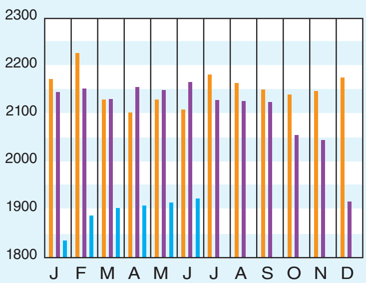
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS			YEAR AGO
CPI output index (2012 = 100)	Jul. '15 = 105.5	Jun. '15 = 105.1	May '15 = 105.0		Jul. '14 = 103.9
CPI value of output, $ billions	Jun. '15 = 1,923.5	May '15 = 1,912.1	Apr. '15 = 1,911.6		Jun. '14 = 2,201.0
CPI operating rate, %	Jul. '15 = 76.4	Jun. '15 = 76.0	May '15 = 76.1		Jul. '14 = 75.4
Producer prices, industrial chemicals (1982 = 100)	Jul. '15 = 247.3	Jun. '15 = 241.4	May '15 = 237.3		Jul. '14 = 295.7
Industrial Production in Manufacturing (2012=100)*	Jul. '15 = 105.7	Jun. '15 = 104.9	May '15 = 105.2		Jul. '14 = 104.2
Hourly earnings index, chemical & allied products (1992 = 100)	Jul. '15 = 159.0	Jun. '15 = 157.6	May '15 = 159.1		Jul. '14 = 156.9
Productivity index, chemicals & allied products (1992 = 100)	Jul. '15 = 122.0	Jun. '15 = 121.3	May '15 = 121.5		Jul. '14 = 121.9

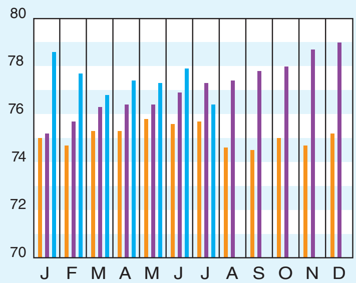
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the June 2015 *CE* Plant Cost Index (CEPCI; top; the most recent available) continued the trend of small monthly declines since the beginning of the year. The June CEPCI is 3.1% lower than the corresponding value from a year ago at the same time. This is a larger gap than the 2.1% for the May year-ago value. The Engineering & Supervision subindex rose slightly in June, but the other subindices saw small declines. Meanwhile, the latest Current Business Indicators (middle) numbers all showed a slight increase compared with the previous month's values. For this month's CBI numbers, the base year for determining the CPI output index and the industrial production in manufacturing were both changed to 2012.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