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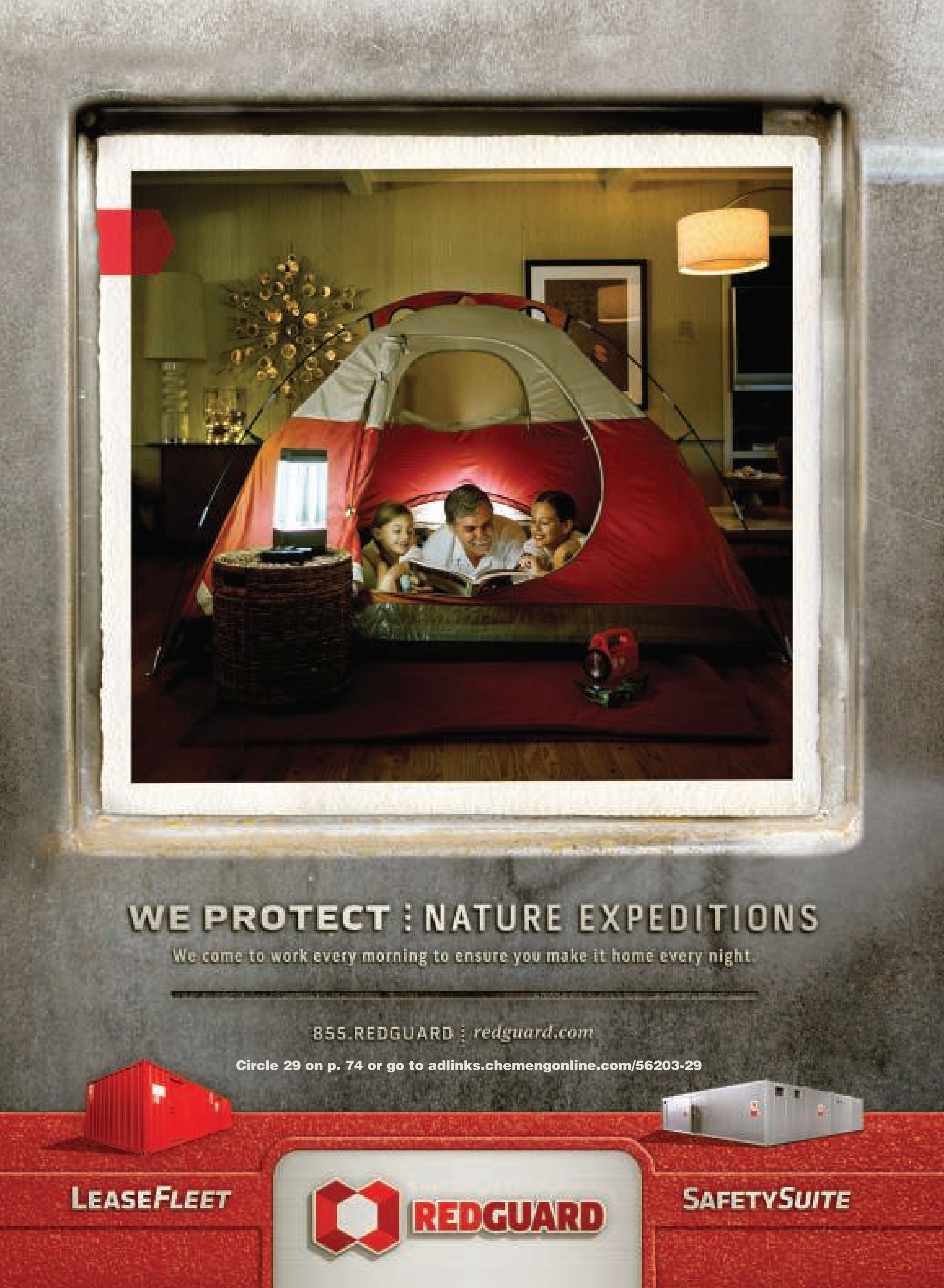
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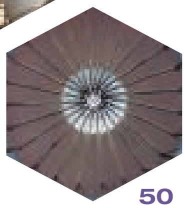
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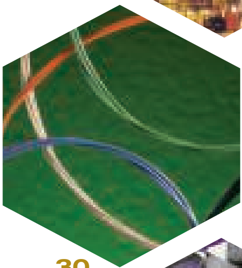

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Editor's Page

Casting a wide net for innovation

I recall from the time that I worked as a research and development (R&D) engineer, the concept of a "rainmaker" — a talented researcher who was challenged to come up with new technologies that could eventually lead to new businesses. Today, crowdsourcing enables companies to tap virtually unlimited sources for ideas. While internal R&D resources are still fundamentally very important to most businesses, crowdsourcing techniques hold great potential for discovery, as well as opportunities for innovative thinkers.

Innovations for water sustainability

Recently, a national (U.S.) competition was launched to cultivate new ideas for improving sustainability in the water industry. Fittingly announced at the Water Environment Federation Technical Exhibition and Conference (Weftec; Chicago, Ill., September 26–30; www.weftec.org), the competition is sponsored by Veolia (Paris, France; www.veolia.com), The Water Council (Milwaukee, Wisc.; www.thewatercouncil.com) and the Wisconsin Economic Development Corp. The program offers a variety of rewards, including $25,000 and $10,000 cash prizes, educational and training opportunities, as well as a year of office space that will be awarded to up to three winners. These incentives are being offered to find innovators and entrepreneurs whose ideas can be fast-tracked. Details about the program, called "Pow! emPowering Opportunities in Water," can be found at www.veolianorthamerica.com/pow.

Tackling CO_2 emissions

In another recent announcement, NRG, a U.S.-based energy company (www.nrg.com) and COSIA (Canada's Oil Sands Innovation Alliance; www.cosia.ca) are co-sponsoring a $20-million XPRIZE (Culver City, Ca.; www.xprize.org) in a competition to address CO_2 emissions from fossil fuels. The goal is to find breakthrough technologies that can convert CO_2 into valuable products. The 4.5-yr competition will include testing the new technologies in either a coal-fired power plant or a natural-gas facility. Details of the Carbon XPRIZE can be found at carbon.xprize.org.

Crowdsourcing for innovation

Crowdsourcing for innovation has been gaining momentum in recent years. Another example is BASF SE's (Ludwigshafen, Germany; www.basf.com) "Open Innovation Contest" for energy storage that was announced in February. This contest called for sustainable technologies to store power and feed it back to the grid. A prize of €100,000 and the opportunity to collaborate with BASF in a research project based on their ideas was offered to winners.

And in an earlier program announced in late 2013, the Dow Chemical Company (www.dow.com) and Innocentive (Waltham, Mass.; www.innocentive.com) offered a $15,000 prize for novel applications for Dow's oil-soluble polyalkylene glycols.

Companies are partnering with groups like Innocentive, XPRIZE and others who can assist in crowdsourcing for innovative ideas. The websites of these crowdsourcing experts reveal the variety of companies that are using this technique. And for the entrepreneurs among us, a look at some of the challenges being offered can open doors to opportunity. ■

Dorothy Lozowski, Editor in Chief


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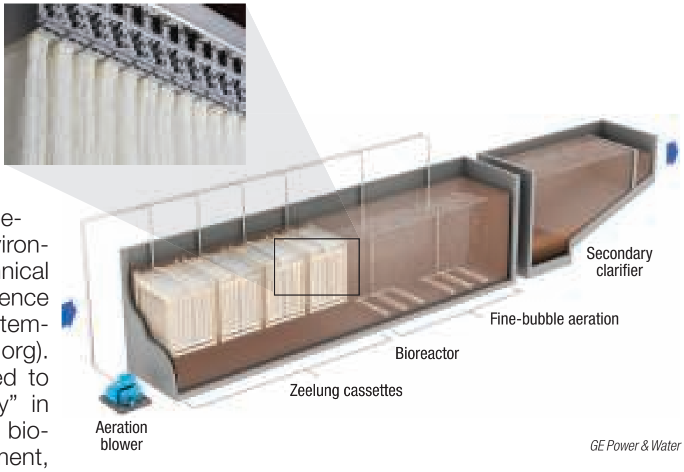
Turning wastewater treatment into resource recovery

Edited by:
Gerald Ondrey

In late September, GE Power & Water (Trevose, Pa.; www.gewater.com) introduced its new Membrane Aerated Biofilm Reactor (MABR) technology, tradenamed ZeeLung, at the Water Environment Federation Technical Exhibition and Conference (Weftec; Chicago, Ill., September 26–30; www.weftec.org). This technology is poised to enable "energy neutrality" in wastewater treatment. In biological wastewater treatment, aeration typically represents 60% of a facility's power usage, and the ZeeLung MABR can reduce the energy needs by a factor of four, according to GE.



GE Power & Water

In conventional biological wastewater treatment, oxygen is delivered to the microorganisms via fine bubble aeration. Much of the O_2, however, is wasted as the bubbles disperse on the surface of the water. The ZeeLung MABR technology replaces this method with a gas-transfer membrane that delivers the O_2 to a biofilm that is attached to the surface of the membrane. Hollow-fiber O_2-permeable membranes are assembled around a core to form a "cord". These flexible, but strong cords are fitted into headers to form a module (photo). Air is distributed to the membranes from the top header and collected in the bottom header. Modules are installed in cassettes for installation into bioreactor tanks (diagram).

The technology is being evaluated by the Metropolitan Water Reclamation District (MWRD) of Greater Chicago in a demonstration project at the O'Brien Water Reclamation Plant in Skokie, Ill. The demonstration project is being run at 500,000 gal/d of water. It is expected that the ZeeLung technology will be commercialized around June of 2016. While the system is initially being targeted for municipal-wastewater treatment plants, the technology also has potential for industrial-wastewater treatment applications wherever oxygen transfer is needed.

A booster bed for CFBs

The efficiency of circulating fluidized-bed (CFB) combustors can be significantly increased by substituting conventional bed material with an ilmenite-based bed material, according to researchers at Chalmers University of Technology (Gothenburg, Sweden; www.chalmers.se). Conventional CFB boilers use silica sand to evenly distribute the heat to the fuel to ensure efficient combustion, which is especially important for coarse fuels, such as wastes or biomass. Chalmer's new bed material is based on the mineral ilmenite — a metal oxide of iron and titanium ($FeTiO_3$). The ilmenite-based bed material has the same heat-distributing role as sand, but with the added benefit of also evenly distributing O_2 to the fuel inside the combustion chamber.

Full-scale trials of the new bed material were performed over three years, first at the Chalmers power plant, and from 2014, in parallel at a commercial plant of Eon Swerge AB (Malmö, Sweden; www.eon.se) — a combined heat and power (CHP) plant, Händelöverket in Norrköping. In one of Händelöverket's five boilers (a 75-MW CFB boiler), sand was replaced with the new bed material. The tests confirmed that "the combustion becomes more uniform and efficient, says Fredrik Lind, product coordinator at Chalmer's Dept. of Energy and Environment. The boiler's total efficiency is increased, and the carbon monoxide emissions lowered "radically," as are problems related to ash fouling, he says.

Eon plans to start using the ilmenite-based bed material in two boilers in Norrköping this year, and has several other plants in line.

NYLON RECYCLING

Validation has been completed, and construction is underway for an industrial-scale facility that will recycle technical textile waste when it starts up in 2016 at a site in Gorzów, Poland. The facility is part of Solvay S.A.'s (Brussels, Belgium; www.solvay.com) Move4Earth project, which is supported by the European Commission's LIFE+ program. The project aims to develop a recycling process to "revalue" technical textile waste into high-quality polyamide 6.6 (PA6.6) grades.

Initially the effort is focused on automobile airbags. More than 70% of these products are made of silicone-coated nylon fabrics, mostly based on PA6.6. Solvay has developed a proprietary process for separating the fabric from the coating, and producing PA6.6 with "no significant loss in material properties," says Solvay.

OER CATALYST

The oxygen evolution reaction (OER; $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$) that occurs during water oxidation is a key energy-conversion reaction for rechargeable metal–air batteries and direct solar water electrolysis. Although ABO_3-type perovskites (where A and B are cations of different size) have been shown to have a high catalytic activity for the OER, they are not stable, therefore rendering them unsuitable for industrial applications.

Now, a team of researchers from Osaka Prefecture University(Japan;www.osakafu-u.ac.jp), in collaboration with the Deutsches Elektronen Syncrotron (Hamburg, Germany; www.desy.de), has synthesized an iron-based catalyst that is both highly active for the OER, as well as being stable.

The catalyst — an Fe^{+4}-based quadruple perovskite,

(Continues on p. 8)

Note: For more information, circle the 56-digit number on p. 74, or use the website designation.

$CaCu_3Fe_4O_{12}$; CCFO — is synthesized using ultrahigh pressure (150,000 atm) and temperature (1,000°C). The covalent bonding network incorporating multiple Cu^{+2} and Fe^{+4} transition metal ions is said to significantly enhance the structural stability of CCFO, which is a key to achieving highly active, long-life catalysts.

In laboratory trials, CCFO was shown to have an OER activity comparable to or exceeding those of state-of-the-art catalysts, such as $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}$ (BSCF), as well as expensive RuO_2.

SOLAR H_2

A combination of concentrator photovoltaic (CPV) modules with electrochemical cells has been shown to electrolyze water into H_2 with a 24.4% efficiency, which is more than twice that observed from existing photocatalyst-based solar-to-H_2 technology. The new world record was achieved by the group of Masakazu Sugiyama at the University of Tokyo (www.ee.t.u-tokyo.ac.jp/~sugiyama/index-e.html), in collaboration with Yasuyuki Ota's group at the University of Miyazaki (both Japan; www.miyazaki-u.ac.jp).

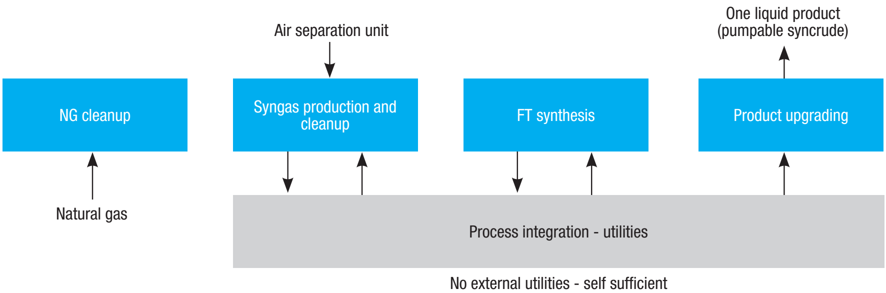
The water-electrolysis system employs high-efficiency CPV modules using InGaP/GaAs/Ge three-junction cells, which have a solar-to-electricity conversion efficiency of about 31%, combined with polymer-electrolyte electrochemical cells.

SYNTHETIC DYES

Archroma (Reinach, Switzerland; www.archroma.com) has introduced a line of six dyes for cellulosic fibers that are made from non-edible waste products in the agricultural and food processing industries, rather than from petroleum products. After four years of research and development, the company patented the synthetic transformation and manufacturing processes that result in the brown, bordeaux, green and grey bio-synthetic dyes. "By using non-edible natural products, such as almond shells, rosemary leaves and saw palmetto as raw materials, we can make dyes that improve sustainability and reduce environmental impact compared to petroleum-derived synthetic dyes," says Nuria Estape, Archroma global promo-

(Continues on p. 14)

Convert wasted natural gas to liquid fuels



A newly launched technology known as Flare Buster is capable of converting natural gas streams, such as flare gas and stranded gas from remote sites, to synthesis gas (syngas) and then to synthetic crude oil via a Fischer-Tropsch (F-T) synthesis process. The skid-mounted and transportable system converts nominally 5 million std ft^3/d of natural gas into 500 bbl/d of synthetic crude oil, adding value to a waste stream and reducing emissions.

Developed jointly by Emerging Fuels Technology (EFT; Broken Arrow, Okla.; www.emergingfuels.com) and Black & Veatch Corp. (B&V; Overland Park, Kan.; www.bv.com), the self-sufficient Flare Buster system is now available in 500-bbl/d incremental sized units that can be combined for higher-volume applications. Customized facilities are also available to meet the specific requirements of the plant.

"Flared gas is lost money," says Doug Miller, vice president of Black & Veatch's oil & gas and energy division. The Flare Buster can help to monetize gas that would otherwise be wasted, and then can be easily moved to another location as needs change, he comments.

Flare Buster (block diagram) initially converts the natural gas feed to syngas by partial oxidation or steam-methane reforming. Next, the syngas is then fed into the system's Advanced Fixed-Bed F-T reactor. In a plug-flow catalyst system, the syngas is converted to synthetic crude oil over a proprietary, highly active, gas-to-liquids (GTL) catalyst developed by EFT. The catalyst is engineered to lead to high yields and favorable economics in this type of application, says B&V's Miller. The synthetic crude produced by the Flare Buster can be further refined to produce a variety of products, such as diesel, jet fuel, lubricant oils, base oils and waxes.

Flare Buster operates without the need for external utilities, and facility capacity can be constructed and adjusted to match the volume of gas from a particular location, says Miller.

Lithium from coal

Coal could become a major source of lithium, according to a team led by professor Shenjun Qin, of Hebei University of Engineering (Handan, China; www.hebeu.edu.cn). From available data, the concentration of lithium in most coal varies between 10 and 50 µg/g. For example, the concentration of lithium in flyash samples is between 65 and 287 µg/g in South Africa and an average of 46 µg/g in China.

Using two analytical techniques — inductively coupled plasma mass spectroscopy (ICP-MS), and ICP atomic emission spectroscopy (ICP-AES) — the team has found Li dispersed, and even anomalously enriched in coal deposits. But in general, it says the analysis for Li has been largely neglected, with no specific discussion reported regarding Li concentrations in coal and coal ash.

The team has also applied two techniques for lithium or aluminium extraction from coal ash. The first involves sintering the ash with sulfur, followed by acid leaching the metal (Li or Al) from the solution. With this extraction process, up to 60% of the metal has been recovered as Li_2CO_3, with a yield of 95.6%. An alternative technique, alkali sintering, avoids the need for the sulfur step, but has shown a lower yield (85.3% yield, with a metal recovery of 55%).

"Although the investigation into Li recovery from coal ash is still at a laboratory scale, it will promote the green and efficient application of coals," says the team.

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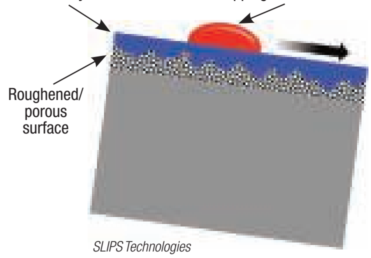
Liquid-infused surfaces move toward commercial applications



SLIPS Technologies

A set of technologies that create an immobilized thin layer of lubricant on a solid surface, thus enabling highly repellent, omniphobic surfaces, has moved closer to commercial application. Known as slippery, liquid-infused porous surfaces (SLIPS), the technologies can be applied to metal, plastic, glass and ceramic surfaces, and can repel a wide range of liquids and biological fouling agents.

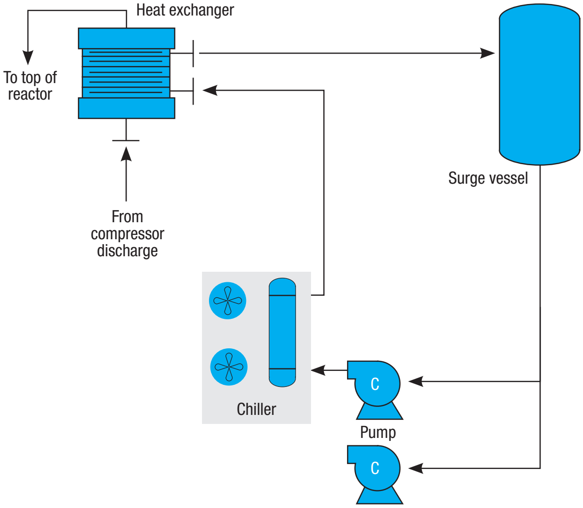
"SLIPS differ fundamentally from other nanostructured repellent surfaces because they maintain a resilient liquid covering over the solid surface, rather than presenting a solid surface to a liquid to be repelled," explains Daniel Behr, CEO of SLIPS Technologies (Cambridge, Mass.; www.slipstechnologies.com), which is commercializing the technology under an exclusive license from Harvard University (Cambridge, Mass.; www.harvard.edu), where SLIPS were first invented. "The surface texture does not have to be highly ordered, as in nanostructured coatings, allowing an easier path to scaling up the technology," he says. (For more on nanostructured, superomniphobic surfaces, see *Chem. Eng.*, January 2015, p. 12).

The general process by which SLIPS are created involves introducing some degree of porosity or roughness to a solid surface, which is then chemically functionalized. The functionalized surface is then infused with a lubricant material, which forms a stable, immobilized and resilient liquid-film overlayer (diagram). "By carefully engineering the surface morphology and chemical functionalization, and matching it to a particular lubricant type, a wide range of SLIPS can be created that could have uses in many applications," says Behr. A major technical hurdle in development was figuring out how to maintain robust and persistent lubricant coatings through non-covalent interactions, says Philseok Kim, a co-inventor of the technology and a co-founder of SLIPS Technologies.

SLIPS applications include promoting the shedding of ice formed on the exterior of heat-exchanger coils in refrigeration, the release of highly viscous materials from industrial equipment such as containers, chutes, molds and others, and preventing the formation of biofilms. The company also received a grant recently for developing SLIPS for preventing the adhesion of barnacles and mussels to ship hulls.

SLIPS Technologies is working with a number of commercial development partners on integrating SLIPS into existing products, and on employing SLIPS in end-use applications, Behr notes.

Streamline turnarounds with faster catalyst cooling



Aggreko North America

A new process technology from Aggreko North America plc (Houston; www.us.aggreko.com) aims to make turnarounds at petroleum refineries more cost-effective by decreasing the time required for catalyst cooling. The catalyst materials used for refining operations, such as hydrotreating, hydrocracking and reforming, operate at very high temperatures, and must be cooled prior to maintenance. As these catalyst beds can contain millions of pounds of material, the cooling process can be one of the most time- and cost-intensive tasks during a turnaround.

Traditionally, a two-step cooling process is employed. The first step circulates hydrogen gas through the reaction loop's recycle-gas compressor, and cools the catalyst bed down to around 200°F. A second step is required to further cool the system for safe maintenance, especially if vessel entry is required. This second step utilizes large volumes of liquid nitrogen, and can take several days.

Aggreko's recently patented process (diagram) simplifies the second step, and eliminates the use of costly N_2. In this process, coolant is circulated through a closed-loop chiller system, cooling down the recycle-gas compressor. The compressor discharge is routed to a downstream heat exchanger, which forces the coldest gas into the top of the reactor bed, and also removes the heat of compression. According to the company, this process cools much faster than nitrogen-based cooling, as demonstrated in one recent application where the nitrogen-free cooling system decreased catalyst temperature from 200 to 80°F in just 11 h. All equipment for the cooling process is provided by Aggreko on a rental basis, and each system is designed to fit the specific application. An important aspect of the design is selecting the proper coolant for the required temperatures — water and glycol mixtures have been commonly used. The coolant is not consumed, and usually does not need to be changed out once the equipment is deployed onsite.

'Switchable solvent' technology is a promising development for advancing forward osmosis

Forward osmosis (FO), whereby a concentrated salt solution is used to "draw" water through a membrane from a less-concentrated salt solution (via osmotic pressure), has the advantage over reverse osmosis (RO) in that high pressures, with the associated pumps and energy requirements, are avoided. In addition, FO can be applied for concentrating brine solutions of much higher concentration (up to 25 wt.%) than seawater — such brines, as are produced in hydraulic fracturing, cannot be treated by RO, says professor Philip Jessop, Dept. of Chemistry, Queen's University (Kingston, Ont., Canada; www.chem.queensu.ca).

However, the main disadvantage with FO has been the cost-intensive step needed to regenerate the draw solution after it has been diluted. Now, a clever method — using a switchable solvent discovered and patented by Jessop — is being developed by Forward Water Technologies (FWT; www.forwardwater.com), the university's spinoff company aiming to commercialize the technology, in cooperation with GreenCentre Canada (both Kingston, Ont.; www.greencentrecanada.com).

Normally, diluted draw solution has to be regenerated by energy-intensive methods, such as evaporation or a temperature increase, or by a capital-intensive step, such as crystallization. Instead, Jessop and colleagues use a solvent that switches between low and high osmotic pressure using CO_2 as the "trigger." Two versions of the process are being investigated, explains Jessop: one uses a gaseous amine (such as trimethylamine), and the other uses a polymeric amine. In both cases, the switchable solvent is made by dissolving the amine in water to form an aqueous solution with relatively low osmotic pressure. Bubbling CO_2 into the solution changes the amine into its bicarbonate salt, thereby "switching on" the high osmotic pressure needed for the draw solution of the FO process. After this draw solution becomes diluted, the solvent is regenerated by simply removing the CO_2 by stripping with air. In the case of the gaseous amine, the amine is removed with the CO_2 — both of which can be recycled. The recovered water is suitable for industrial applications.

In laboratory trials, the combined FO/switchable-solvent technology has been shown to reduce the volume of 10-wt.% brine wastewater by more than 50%, while producing clean water with less than 1,000 parts per million (ppm) salt content, says FWT CEO C. Howie Honeyman. FWT has just commissioned a scalable 20-L/h miniplant to gather data needed for scaling up the process, as well as for evaluating the economics of the process.

tion manager. And the dyes perform equally well to the existing range of sulfur dyes derived from conventional raw materials, adds Albert Llort, product manager for special dyes at Archroma. The company is now working on a blue dye and expanding the range of waste natural materials. Archroma is also working with clothing and textile makers on an authentication project that guarantees the sustainably sourced dyes.

NEW FLAME RETARDANT

Researchers at the University of Texas at Austin (www.utexas.edu) have found that a synthetic coating of polydopamine — derived from the natural compound dopamine — can be used as a highly effective, water-applied flame retardant for polyurethane foam. The researchers believe their dopamine-based nanocoating could be used in lieu of conventional flame retardants.

Using far less polydopamine by weight than typical of conventional flame retardant additives, the team found that the polydopamine coating on foams leads to a 67% reduction in peak heat-release rate, a measure of fire intensity and imminent danger to building occupants or firefighters. The polydopamine flame retardant's ability to reduce the fire's intensity is about 20% better than existing flame retardants commonly used today.

This chemical-free disinfection media requires no power

Surface-modified ceramic materials have been developed to disinfect water and air and other fluids without requiring additional chemicals or energy input. Developed by Claire Technologies (Raleigh, N.C.; www.claire-tech.com), the disinfection media consist of silica- and alumina-based pellets that have been modified to have powerful cationic surface sites. When they come into contact with microorganisms, the cationic sites at the ceramics' surfaces pull electrons from the cells of the microbe, destroying them.

"The excellent germicidal properties of silver have been known for quite some time, but it has proven difficult to bring a silver-based disinfection system to industrial scale," explains Cristian Chis, chief technology officer of Claire. "We have developed a process for coating the surface of the ceramic so that we can attach silver atoms covalently," Chis says. In this way, the silver can kill microbes on contact, but does not leach out of the pellets.

In tests, the technology has demonstrated 5- to 10-log reductions in a wide range of bacteria, viruses, yeasts and micro-algae, including *Escherichia coli*, *Staphylococcus aureus, Pseudomonas aeruginosa, Legionella adelaidensis* and others.

Claire has built a production-scale facility for the disinfection media and is now testing its products for a host of applications, including wastewater disinfection, well water sanitation, drinking water disinfection, fighting Légionnaires infections, cooling-tower water disinfection, cooling oil disinfection, ballast-water treatment and others. In February 2015, Claire entered into a Cooperative Research and Development Agreement (CRADA) with the U.S. Environmental Protection Agency (www.epa.gov) involving wastewater and mobile emergency water-treatment systems. ■

Business News

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Plant Watch

BASF and Sinopec inaugurate world-scale isononanol plant in Maoming

October 12, 2015 — BASF SE (Ludwigshafen, Germany; www.basf.com) and China Petroleum & Chemical Corp. (Sinopec; Beijing; www.sinopec.com) have inaugurated a world-scale isononanol (INA) plant in Maoming, China. The plant has INA production capacity of 180,000 metric tons per year (m.t./yr), and is said to be the first INA plant in China.

Air Liquide signs longterm contract with major petroleum group in China

October 12, 2015 — Air Liquide (Paris, France; www.airliquide.com) signed a longterm contract with Yan'an Energy and Chemical Co. in which Air Liquide will invest around €80 million in two new air separation units (ASUs), with a total capacity of 2,800 m.t./d of oxygen. Expected to start operations in early 2018, the new ASUs will supply air gases for a plant that will produce 600,000 m.t./yr of olefins.

Jacobs awarded EPCM contract from Nippon Shokubai Europe

October 6, 2015 — Jacobs Engineering Group Inc. (Pasadena, Calif.; www.jacobs.com) has received a contract from Nippon Shokubai Europe N.V. for detailed engineering, procurement and construction management (EPCM) services for the expansion of its superabsorbent polymer plant and a new acrylic acid plant at a site in Zwijndrecht (Antwerp), Belgium. The project's total investment is approximately $390 million. Completion is expected in October 2017.

Evonik plans to build additional methionine plant in Singapore

October 1, 2015 — Evonik Industries AG (Essen, Germany; www.evonik.com) has started the planning stage for the construction of an additional plant complex in Singapore to produce the amino acid D,L-methionine. The new plant will have a production capacity of 150,000 m.t./yr and is expected to start operations in 2019.

Kuraray to expand production capacity for optical-use base films in Japan

October 1, 2015 — Kuraray Co. (Tokyo, Japan; www.kuraray.co.jp/en) will expand production of optical-use polyvinyl alcohol (poval) film at its facility in Saijo, Japan. The production capacity for these films will increase from 212 to 232 million m^2/yr. The expanded operations are planned to commence in early 2017.

Mitsubishi Polyester Film invests in South Carolina plant expansion

September 30, 2015 — Mitsubishi Polyester Film, Inc. (Greer, S.C.; www.m-petfilm.com) will invest $100 million to increase its capacity for biaxially oriented polyester film at its plant in Greer, S.C. The investment will include a new film-production line scheduled to start up in mid-2017.

Inovyn to build large-scale potassium hydroxide plant in Belgium

September 25, 2015 — Inovyn (www.inovyn.com), a joint venture (JV) between Solvay S.A. (Brussels, Belgium; www.solvay.com) and Ineos Technologies (Rolle, Switzerland; www.ineos.com), is planning a major investment in a large-scale potassium hydroxide (KOH) production facility at its Antwerp/Lillo site in Belgium. The investment consists of a KOH plant with a capacity of 160,000 m.t./yr that will go onstream in 2017.

BASF to build production facility based on Genomatica's renewable BDO technology

September 24, 2015 — Under the terms of an expanded license agreement, BASF will build a world-scale production facility that will use Genomatica's (San Diego, Calif.; www.genomatica.com) process to manufacture renewable 1,4-butanediol (BDO). BASF has secured rights to allow production of up to 75,000 m.t./yr of BDO.

CB&I awarded FEED contract for ethylene cracker project in Texas

September 23, 2015 — CB&I (The Woodlands, Tex.; www.cbi.com) has been awarded a contract by Total to provide its proprietary ethylene technology and front-end engineering and design (FEED) services for a proposed new ethane cracker located in Port Arthur, Tex. The proposed cracker will have a capacity of 1 million m.t./yr of ethylene.

PPG completes expansion of coatings facility in Spain

September 17, 2015 — PPG Industries, Inc. (Pittsburgh, Pa.; www.ppg.com) announced the completion of a $3.8-million expansion at its coatings manufacturing facility in Laguna de Duero, Valladolid, Spain. The investment provides new mixing and blending equipment at the facility that will support an 80% increase in annual coatings-production capacity.

Mergers & Acquisitions

GE to acquire membrane manufacturer IMT Solutions

October 5, 2015 — GE Power & Water (Schenectady, N.Y.; www.gepower.com) has agreed to acquire IMT Solutions, a Netherlands-based manufacturer of filtration membranes for water treatment. With this acquisition, GE expands its existing advanced ultrafiltration hollow-fiber membrane portfolio.

ThyssenKrupp merges plant technology businesses in France

October 1, 2015 — ThyssenKrupp Industrial Solutions AG (Essen, Germany; www.thyssenkrupp-industrial-solutions.com) is strengthening its plant technology capabilities in France by merging the formerly separate entities Polysius and KH Mineral to become ThyssenKrupp Industrial Solutions (France).

Axiall's aromatics business acquired by Ineos

October 1, 2015 — Ineos Technologies has acquired the aromatics business of Axiall Corp. (Atlanta, Ga.; www.axiall.com) for $52.4 million. The acquisition comprises a 900,000-m.t./yr cumene production plant based in Pasadena, Tex. In addition, the phenol, acetone and alpha-methylstyrene business will transfer to the Ineos Phenol facility in Mobile, Ala.

ExxonMobil to sell Torrance refinery to PBF Energy

October 1, 2015 — ExxonMobil Corp. (Irving, Tex.; www.exxonmobil.com) has reached an agreement with PBF Energy, Inc. for the sale and purchase of its petroleum refinery in Torrance, Calif., as well as other associated California-based assets. Subject to repairs to the refinery's electrostatic precipitator and regulatory approval, change-in-control is anticipated to take place by mid-2016.

Kraton to acquire Arizona Chemical for $1.37 billion

September 30, 2015 — Kraton Performance Polymers, Inc. (Houston; www.kraton.com) has entered into a definitive agreement to acquire all of the capital stock of privately held Arizona Chemical Holdings Corp. for a cash purchase price of $1.37 billion. Arizona Chemical is a producer of high-value performance products and specialty chemicals made from non-hydrocarbon, renewable raw materials.

Praxair expands business in Peru with Tecnogas acquisition

September 24, 2015 — Praxair, Inc. (Danbury, Conn.; www.praxair.com) has acquired Tecnogas, a producer and distributor of carbon dioxide and industrial gases in Peru. Tecnogas owns and operates three carbon dioxide production plants that Praxair will use to serve the growing demand for the gas in the country.

ABB to collaborate with Werum IT solutions

September 24, 2015 — ABB (Zurich, Switzerland; www.abb.com) has signed a memorandum of understanding with Werum IT Solutions GmbH, a supplier of pharmaceutical manufacturing-execution systems, to collaborate on distributed control-system (DCS) solutions for the life-science industries, providing expertise in DCS and production-management software.

Lanxess and Saudi Aramco create JV for synthetic rubber

September 22, 2015 — Lanxess AG (Cologne, Germany; www.lanxess.com) and Saudi Aramco's subsidiary Aramco Overseas Co. plan to establish a JV for synthetic rubber, in which each party will hold a 50% interest. The transaction is expected to be completed in the first half of 2016. The JV is valued at €2.75 billion. ■

Mary Page Bailey

CPI Salaries Hold Steady; Workforce Solutions Expand

Conditions in the U.S. CPI continue to support high salaries for engineers and skilled technical workers, but conditions also continue to sustain ongoing workforce challenges

IN BRIEF

SOLID, BUT ERRATIC LABOR MARKET

SALARY SURVEY DATA

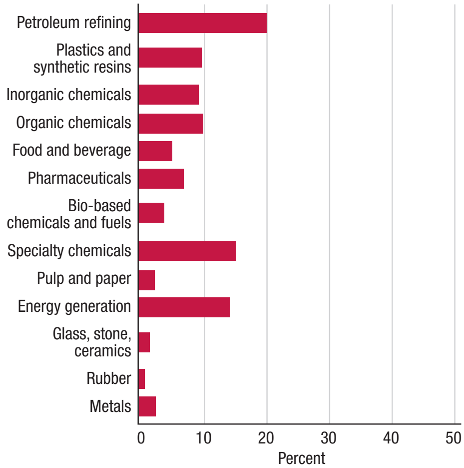
WORKFORCE QUESTIONS

CONSTRUCTION INVESTMENTS

EDUCATION EXPANSION

Engineering expertise and technical know-how continue to be in high demand in the chemical process industries (CPI), and that is keeping upward pressure on salaries for chemical engineers. Survey data from a number of sources indicate that CPI salaries remain strong in 2015 and unemployment remains low. Ongoing capital investments to take advantage of inexpensive and plentiful natural gas from shale deposits continue to cast a large shadow when considering current workforce issues, especially in areas of high activity, such as Louisiana and Texas. Responses to workforce issues surrounding the supply of skilled labor for construction and operation of new facilities are now maturing and expanding, but the scope of the challenge remains large, and is complicated by the depressed price of crude petroleum observed for the past year.

FIGURE 1. INDUSTRY SECTORS OF RESPONDENTS TO THE 2015 *CE* SALARY AND WORKFORCE SURVEY (GLOBAL)



Solid, but erratic labor market

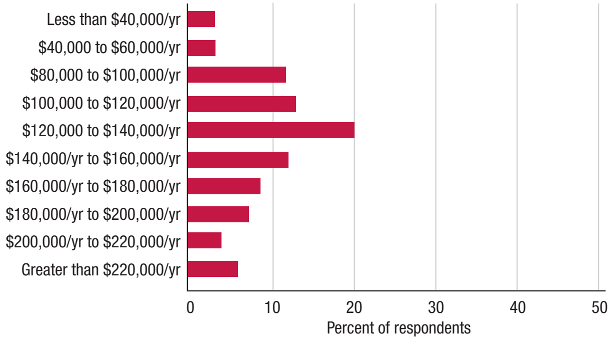
By many measures, 2015 is a good time to be a chemical engineer in the U.S., and a good time to be employed in the CPI in general. With unemployment among engineers very low (estimated at 1% or less), compensation levels currently remain very strong for those with degrees and experience in chemical engineering. A large part of the strong demand for engineers in the CPI is driven by investments made in chemical manufacturing to take advantage of inexpensive natural gas from shale deposits in the U.S. The American Chemistry Council (ACC; Washington, D.C.; www.americanchemistry.com) has found that jobs in the chemical industry have been added over the past two years, and "as new production of basic chemicals, resins, fertilizers and other shale-advantaged chemicals comes online, new jobs will be created to support the expansion."

However, the depressed prices for crude petroleum since late 2014 have complicated the labor market somewhat for workers in the CPI. Lower oil prices have made life more difficult for the U.S. oil-and-gas sector, and have meant a partial erosion of the competitive advantage for U.S. chemical makers. Cheaper oil means lower feedstock costs for those making ethylene from naphtha, for example, which eats into the advantage enjoyed by U.S. petrochemical companies using ethane and other natural gas from shale as a feedstock.

"The labor market for chemical engineers seems to be behaving somewhat strangely this year, due in significant part to the drop in crude oil prices we have seen, among other factors," says Adam Krueger, recruiter with Sun Recruiting Inc. (Chicago, Ill.; www.sunrecruiting.com). "It's been erratic in terms of the timing of hiring patterns." Although it is still difficult for CPI companies to find talented workers, the hiring pace has slowed over the past year, Krueger says.

In the U.S., the greatest demand for chemical engineering jobs seems to be in the Southeast and Midwest regions, with less in

FIGURE 2. SALARY RANGE REPORTED BY RESPONDENTS TO 2015 *CE* SALARY SURVEY (U.S. AND CANADA)



the Northeast and Gulf Coast regions, where traditional hotbeds of engineering jobs, such as Houston and Baton Rouge, La. have seen less than the normal number of chemical engineering job searches, Krueger says. Part of the explanation could be that chemical-manufacturing companies have been able to locate engineers that may have been laid off from jobs in the upstream oil-and-gas sector as the petroleum prices remain low, reducing their need for job search consultants.

The discrepancy between upstream and downstream sectors of the market has been observed over the past year, according to Krueger. "Companies involved in the oil-and-gas sector and in petroleum refining are generally hiring at a much lower level this year compared to other recent years, while companies making specialty chemicals, bio-based chemicals and inorganic chemicals are hiring at a much higher rate, comparatively," Krueger says.

Despite the uneven nature of hiring in 2015, there remains a huge lack of talented engineers in the middle experience levels. "Everyone is looking for engineers with 5 to 20 years of experience," Krueger says. Project engineers are in demand, as are maintenance and reliability engineers, automation and control engineers and process design engineers," he points out.

"There's still upward pressure on salaries for engineers in the CPI," Krueger says, "I'm constantly having to ask client companies if they can go higher in salary to land the best talent."

Salary survey data

Surveys can provide data surrounding the salaries of engineers working in the CPI. Two are discussed here.

A survey conducted by *Chemical Engineering* in October 2015 received close to 1,100 responses from CPI workers around the world (Figure 1). The average salary among all respondents that worked full time, including several hundred international respondents, was $104,055, down slightly from the $109,300 average from a similar *CE* survey last year. For respondents in the U.S. and Canada, the average salary was $125,990, down 0.5% from the $126,700 average from last year. The median salary was $120,000. The salaries reported in the U.S. outpaced those reported in Western Europe, where the average was $87,190/yr.

Multiple years of on-the-job experience translates into large pay increases. For U.S. and Canada respondents

EDUCATION AND INDUSTRY

The workforce situation in Louisiana and Texas is an important part of a larger conversation in the U.S. regarding the connection between industry and education and how we approach the education of technically skilled workers.

"There's a profound mismatch in the U.S. between the education we provide to students and the needs of the workforce," says William Symonds, director of the Global Pathways Institute (GPI; www.globalpathwaysinstitute.org), which is based at Arizona State University (Tempe, Ariz.; www.asu.edu). "As a society, we put almost no resources into promoting career literacy and helping people make informed career decisions."

The way those issues are addressed will affect the workforce of the CPI. Symonds thinks that to address the issue in a permanent way, nationally, the country needs to place far more emphasis on career literacy — equipping students with the knowledge, tools and support they need to make good career decisions. In addition, we need to greatly expand work-based learning, including internships and apprenticeships. This is especially important in training engineers. "Engineering schools in the U.S. have not emphasized work-based learning nearly enough," he says. "A key initiative [that the GPI has] is to form partnerships with engineering schools to provide more opportunities for intense, long-term, meaningful internships." This would be a very effective strategy for exposing students to chemical engineering, as well as for helping companies identify promising candidates to hire.

He also advocates for CPI companies to be even more proactive about attracting students. Most high school students take chemistry, he points out, but the subject is generally taught as an abstract subject. "We're not talking to students about the opportunities to work in chemistry," Symonds says.

"Chemical engineering is not perceived as a 'sexy' industry or career path, but it is of vital importance to almost every aspect of our modern lives. We need programs to educate students on the import roles that chemical engineers play in our lives," Symonds remarks.

"We need a cultural revolution in career awareness and literacy. In Germany and Switzerland and other Northern European countries, they do a much better job of linking education to the workforce. Students are put into the college preparatory track or into a vocational track, where they are given on-the-job training while they are learning.

"Students are made to believe that all jobs require a four-year degree, but the reality is that many jobs don't require one," Symonds says. "What they require is advanced technical skills." GPI is working with several other national organizations to create a national coalition to promote career awareness. The coalition is planning to hold a major meeting next February at the U.S. Chamber of Commerce (Washington, D.C.; www.uschamber.com). Companies or organizations interested in getting involved can contact Symonds (william.symonds@asu.edu).

Texas and Louisiana are among the states looking to address the issue through state legislation. In Texas, for example, House Bill 5 was passed in 2013. It is an industry-driven piece of legislation aimed at renewing interest in technical programs for middle schools. Louisiana also has legislation for technical training in high schools.

with 0–3 years of engineering experience, the average salary is $79,200/yr, while the average salary swells to $105,300/yr for those with 8–15 years of experience.

Forty-five percent of survey respondents working full time reported that their salary fell somewhere between $100,000 and $200,000 annually, with 14.3% in the $100,000–$120,000 range and 10% in the $120,000 to $140,000 range. Almost 18%, however, reported salaries of less than $40,000/yr. Those respondents hailed mostly from South America, Mexico and Central America, Southeast and Central Asia. Close to 5% of survey takers reported annual salaries of greater than $200,000. Salaries differed somewhat by job function (Figure 2 and Table 1).

Full time employment was reported by 92.6% of respondents to the *CE* survey, while another 4.0% said they worked part time. Part-time incomes were not included in calculating average salaries. Retired workers made up 2.3% of the respondent pool, while those reporting unemployed status was only 1.0%.

Fifty-two percent of respondents hold a bachelor's degree, (avg. U.S. salary $120,229), while 36.4% have a master's degree (avg. salary $132,686), and 10.5% have a Ph.D ($143,517). Associate's degrees were reported by 1.0% of respondents.

Going forward into next year, 45.2% of respondents said they anticipated their salary to be higher next year than this one, while 44.5% thought their salary would remain about the same. Only 10.3% anticipated a lower salary next year, according to the survey results.

Another recent survey, conducted earlier this year by the American Institute of Chemical Engineers (AIChE; New York; www.aiche.org), suggests a continued upward trend for salaries of its members. The survey found that the median salary for chemical engineers responding rose by 5.8% over the median value from 2013, when the survey was last conducted.

Workforce questions

In addition to the salary-related questions, the *CE* survey also inquired about other workforce-related topics, including recent retirements and hires made by the respondents' employers. For hires, close to 33% of respondents said they estimated that their employers had hired more than 15 engineers and technical staff over the past year. Almost 92% of survey takers said their employer had made at least one hire in the past year. Perhaps somewhat correspondingly, 28.4% of respondents said their company had experienced greater than 15 retirements over the past year, and 80% said their company had seen at least one person retire.

Retirements. The survey also asked to what extent those retirements affected companies' operations, an issue that has been important in the CPI for the past several years. Those reporting that retirements had "greatly affected" their company totaled 16.0%, while those saying retirements had "somewhat affected" their company totaled 41.9%. Just over 25% said that retirements had only "minimally affected" their company and 16.5% said retirements had not affected their company at all.

Skills. The survey also asked to what extent respondents' companies have been affected by a shortage of skilled trade workers, which has also been a much-discussed topic in the U.S. manufacturing and industry sectors, in general. Almost 63% of respondents said that a shortage of skilled trade workers had either greatly affected (17.6%) or somewhat affected (45.22%) their companies' businesses, while 22.9% said the issue had a minimal effect and 14.2% said a lack of skilled worker had no effect on their companies in the past year.

Experience. Finally, the *CE* survey asked about demand for engineers with mid-level experience. In answering this question, 20.8% of respondents said their employer had been "highly affected" by an inability to hire engineers with mid-level experience, and 42% said their company was "somewhat affected." On the other hand, 22.2% said the availability of mid-career engineers had only a minimal effect, and 15% said that it had no effect at all.

TABLE 1. AVERAGE SALARY BY AREA OF WORK

Job function / Area of work	Average salary 2015 (*CE* survey)
Process operations	$113,520
Equipment and maintenance	$123,000
Product design and process design	$119,820
Consulting	$144,355
Environmental, Health and Safety/ Security	$121,350
Research and development	$125,425
Plant management	$139,246

Average salaries were calculated for those U.S. and Canada respondents who indicated a job-function area on the CE survey

Construction investments

A major factor in current CPI workforce issues over the past five years has been the investment in capital projects positioned to take advantage of inexpensive shale gas. "The natural-gas-driven wave of investment is like nothing we've ever seen before," says Louisiana economist Loren Scott.

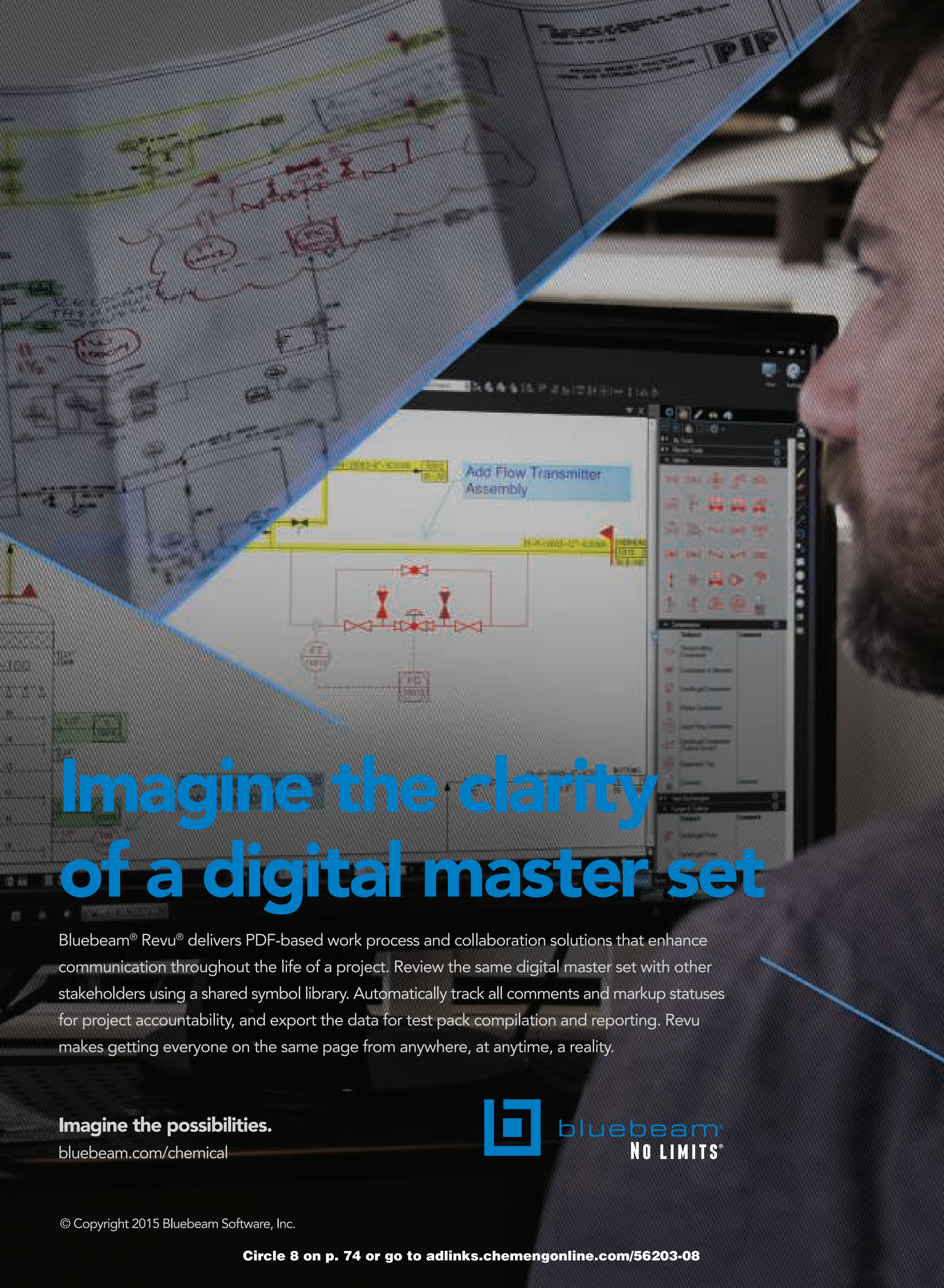
Two regions that offer a window into how the wave of investment is affecting the labor market — and vice versa — are southeast Texas and Louisiana, particularly the areas around Baton Rouge, New Orleans and Lake Charles. "In the past, an annual industrial investment of $5 billion would have been considered a good year," Scott remarks, but Louisiana alone has seen over $145 billion of industrial investment over the past two and half years, so the scope is huge."

"Southeast Texas is similar to Louisiana in terms of the level of investment and the number of construction projects, but other states are not even close to those areas in scope of industrial expansion," Scott says.

Scott describes the situation in Louisiana as highly concentrated by industry and also by geography. The majority of industrial construction projects are centered around the manufacture of petrochemicals ($50.7 billion worth of investment in La.) and around facilities for the export of liquefied natural gas (LNG; $70.2 billion). Geographically, the investments are concentrated around the corridor from Baton Rouge to New Orleans ($44.5 billion) along the Mississippi River, and the Lake Charles region ($96.6 billion) in southwest Louisiana.

Statewide, of the $145.4 billion in announced industrial capital investment, $62.3 billion is accounted for in projects that are either currently under construction or have been completed, while $83.1 billion is accounted for in projects that are in the front-end engineering and design (FEED) stage.

This means that there is a potential for "a whole lot more demand for



workers," beyond even what has been required so far, Scott says. "Construction investment is still going."

The construction is also being affected by the low crude prices also, with subsequent effects on the labor market. "Some FEED-stage projects are hitting the brakes because of the low price of crude oil," Scott notes. "There has been some hesitation this year on going forward, in an effort to see where the oil prices will settle."

"However, some layoffs in the oil & gas sector are benefitting the labor supply for the chemical industry," Scott says.

Education expansion

To meet the workforce needs of industry in areas such as those discussed above, community colleges and technical schools have played an important role in training the skilled workers that are needed not only for the construction projects, but also for operations and maintenance personnel that are needed once the projects come online. At this point, the workforce development efforts to train for high-demand positions, such as process operators and instrumentation technicians, are robust, with a number of programs having been established over the past several years across many campuses. More recent efforts have been aimed at expanding the existing programs to accommodate more students and at ensuring the quality of the education.

"With the billions of dollars in investment coming in for construction projects in the CPI, there are huge needs for construction trade work now," says Monty Sullivan, president of the Louisiana Community and Technical College System (LCTCS). "Once each project is completed, there will be a large demand for process operators and maintenance personnel, and we are expanding programs and standardizing curricula to train people with the skills that industry needs."

"The demand has not slowed down," adds Debi Jordan, executive director of workforce and community development at Lee College (Baytown, Tex.; www.lee.edu).

LCTCS's Sullivan says, "Over the past seven years, we have actually cut the number of programs offered across our colleges significantly (500 programs since 2008), but we have still grown the enrollment in programs that are in line with what local industry is asking for, such as process-operator certification programs."

"We feel that our educational programs are aligned more than ever before with industry needs," he adds.

At Lee College, Jordan says that since the number of job vacancies still outpaces the number of graduates, the college is increasing offerings for working adults to return to school and obtain training that qualifies them to work in the CPI. Lee College has also built new laboratories for hands-on training in machining, pipefitting, welding and millwright skills. The new laboratories will open for students in January 2016. Also, the college has completed a $1.5-million renovation of its on-campus pilot plant and developed a new certificate program that combines instrumentation technology, electrical technology and analyzer technology, Jordan says.

As enrollment grows, efforts to work with industry partners in assembling specific and customized training curricula are also expanding. For example, LCTCS's Sullivan says "A situation that could call for customized training might be a particular new capital investment that has specific training needs."

An ongoing issue associated with expanding training programs is locating qualified faculty to teach the courses. Lee College is working to expand two of its most popular programs currently — the process technology program and the instrumentation technician program. "The barriers to growing those programs are the lack of qualified faculty to teach the courses," says Lee's Jordan. Lee is working with the other eight community colleges on the Texas Gulf Coast to address this challenge. Technical faculty recruitment is a major initiative of the Community College Petrochemical Initiative (CCPI), a consortium launched by a $1.5-million grant from ExxonMobil to attract and train the next generation of petrochemical and industrial construction workers.

"Finding qualified faculty is a limiting factor," agrees LCTCS's Sullivan. "We are trying to attract recently retired industry workers, who have unparalleled practical experience, to come back and teach students."

Another challenge has been the depressed crude-oil prices and subsequent layoffs in the oil-and-gas sector. "The layoffs in O&G have been kind of a curveball this year," says Jordan, but the CCPI has begun work on skills-mapping for jobs on the upstream side to technical jobs on the downstream side to identify possible opportunities for short-term training programs that the college could put together to fill vacancies in the downstream labor market.

"On the industry side, the biggest concern is ensuring the quality of the workforce," says Connie Fabré, executive director of the Greater Baton Rouge Industry Alliance (GBRIA), a 45-year-old organization designed to assist the industrial workforce in the region, which is primarily petrochemical. "So we are very focused on coordinating the involvement of industry members to engage with high schools, trade schools and community and technical colleges."

Also, since there are now, and will continue to be, a lot of new workers on the job, concerns over safety are heightened, Fabré says, and the need for supervisory training is also increased because of the retirements of highly experienced workers.

"We are also looking at specialty needs for industry," Fabre points out, and looking to identify training gaps. For example, she says, GBRIA is developing specific training for workers in areas of CPI plants where high-voltage electrical systems are used, and to train workers who can perform non-destructive testing. ■

Scott Jenkins

EPA Bumps Up Enforcement Efforts

Tighter enforcement requires up-to-date monitoring and control equipment

IN BRIEF

MONITORING INSTRUMENTATION

EMISSION AND CONTROL TECHNOLOGIES

AUTOMATION AND SOFTWARE

With stricter emissions regulations on the horizon and with the U.S. Environmental Protection Agency (EPA; Washington, D.C.; www.epa.gov) actively enforcing ones, the chemical process industries (CPI) can not sit back and relax. The EPA has been actively cracking down on the enforcement of existing regulations and is paying closer attention to reporting and quality assurance of the measurements and information being reported. So what does this mean for chemical processors? It necessitates the continued use of top-notch environmental monitoring and control technologies, as well as solutions that provide more accurate and timely reporting of data. This article examines the newest trends in monitoring, control, software and solutions designed to ensure compliance.

Monitoring instrumentation

When it comes to monitoring, processors tend to be moving away from traditional instruments toward newer, more accurate and reliable methods, including laser-based devices. "The real challenge with traditional methods of monitoring is in the sample conditioning system, which includes the probe, the probe filter, the pump and associated moving parts," explains Warren Dean, senior strategic sales support with Siemens Corp. (Alpharetta, Ga.; www.usa.siemens.com). "And those parts become even less reliable when measuring reactive components."

To overcome this obstacle, he says instrumentation providers have devised non-traditional ways, including laser technologies, to measure these components in situ. "Tunable-diode laser (TDL) analyzers are excellent at accurately, effectively and reliably measuring ammonia and other highly reactive gases thanks to the laser technology," explains Dean.

Siemens' Sitrans LDS 6 TDL instrument (Figure 1) is designed to measure the necessary components directly in the stack, duct or process stream without any sample handling or conditioning system. The TDL measurement technique allows measurement of ammonia, hydrogen chloride, oxygen, carbon monoxide and carbon dioxide in extremely dirty, dusty or corrosive samples where an extractive sampling system would quickly fail or require constant maintenance. The LDS 6 has an internal reference cell for long-term stability and lifetime on-line, continuous, automatic calibration requiring no calibration gas. This technology ensures reliability and accuracy of the measurements.


Siemens Corp.

FIGURE 1. Siemens' Sitrans LDS 6 TDL instrument is designed to measure the necessary components directly in the stack without any sample handling or conditioning system

The Rosemount Analytical division of Emerson Process Management (Irvine, Calif.; www.emersonprocess.com) is also turning to laser technologies in the form of quantum cascade lasers (QCL; Figure 2). The technology is based upon TDL absorption spectroscopy (TDLAS) and replaces other measurement techniques, such as paramagnetic detectors and chemiluminescence. QCL offers multi-element detection, high accuracy, wide dynamic range, low maintenance and a long lifecycle. Unlike TDLAS, QCL doesn't require cryogenic cooling.

QCL technology features a cascade of electrons down a series of quantum wells, which result from the growth of very thin layers of semiconductor material. Traditional single electron-hole recombination methods can only produce a single photon, whereas the quantum cascade laser can cascade down between 20 and 100 quantum wells, producing a photon at each step. This technology

Emerson Process Management

FIGURE 2. Emerson Process Management's quantum-cascade laser instrument features multi-element detection, high accuracy, wide dynamic range, low maintenance and a long lifecycle

produces an electron "waterfall" that provides a step change in performance in terms of efficiency, enabling QCL to emit several Watts of peak power in pulsed operation and tens of milliwatts continuous wave. All this translates, according to Ruth Lindley, product manager, into the ability to collect up to a million measurements per second and measure up to 20 gases simultaneously.

"This means processors can use just one analyzer to reliably and accurately measure multiple gases," says Lindley. "The advantage is that we can measure the majority of the components people must monitor, such as oxides of nitrogen (NOx), sulfur oxides (SOx), CO, CO_2, ammonia and oxygen. Replacing multiple analyzers with a single solution is not only cost competitive, but it simplifies the measurement process."

Golder Associates

FIGURE 3. Chemical processors may begin to move away from point emissions monitoring to whole-site footprints via the use of remote sensing technologies like drones and lasers, according to experts at Golder Associates

And, lasers are expected to play a huge role in the very near future of measurement technology, as well. Sam Arnold, senior atmospheric scientist with Golder Associates (Nottingham, U.K.; www.golder.com) says, "Chemical processors may begin to move away from point emissions monitoring to whole-site footprints via the use of remote sensing technologies like drones and lasers (Figure 3). Monitoring the average emissions of a whole site with drones or lasers has the advantage over point monitoring in that it helps avoid having to take compliance actions based upon the measurements of single pieces of equipment that could be outliers.

"The industry is increasingly innovating in technology and turning to this type of monitoring to stay at the forefront of regulatory compliance on emissions controls," says Arnold.

Emissions control technologies

Emissions control is one of the areas where EPA is most likely to crack down on existing regulations, which could result in the need to upgrade to one of today's more efficient and certifiable options.

For example, Scott Bayon, director of sales with Anguil Environmental (Milwaukee, Wis.; www.anguil.com), says many processing facilities that had been flaring emissions are being forced to look at more-modern control technologies where it is possible to accurately measure what is coming into the system and what is coming out of the system to ensure destruction efficiency.

In addition, many of the oxidizer technologies installed 20 years ago are reaching the end of their useful life, he says. This means that when attempting to amend air permits, many processors are finding that they need to replace lower-efficiency existing equipment with today's more efficient models, says Bayon. "The 95% destruction efficiency achieved by older technology might have been the gold standard when it was installed 20 years ago, but today

Anguil Enviornmental

FIGURE 4. Regenerative thermal oxidizers provide a cost-effective-emission control solution as they achieve 99% destruction efficiency

99-plus percent efficiency is easily achievable and is what regulatory agencies require."

For this reason, many processors are moving away from catalytic oxidizers toward thermal oxidizers. Bayon says regenerative thermal oxidizers (RTOs; Figure 4) provide a cost-effective solution as they achieve 99% destruction efficiency of hazardous air pollutants (HAPs), volatile organic compounds (VOCs) and odorous emissions without the use of a catalyst. RTOs achieve emission destruction using a mix of temperature, residence time, turbulence and oxygen to convert pollutants into carbon dioxide and water vapor.

Vipul Patel, project manager and environmental specialist with Epcon Industrial Systems (The Woodlands, Tex.; www.epconlp.com) says that direct-fired oxidizers (Figure 5) may be the preferred solution when there is a very high VOC or hydrocarbon load, as well as fluctuating operating conditions. In this technology, flame arrestors are installed between the vapor source and the thermal oxidizer. Burner capacities in the combustion chamber varies based on the size of the system and the VOC loading. Operating temperatures range from 1,400 to 1,800°F, and gas residence times are typically 1 s, or more. The conditions cause the process stream's molecular structure to break down into simple CO_2 and water vapor.

Patel acknowledges that this technology may use a lot of fuel, but says the solution is often offered as part of a package that features heat recovery equipment intended to reduce overall fuel consumption of the plant by using the waste heat to provide steam, hot water or hot air to other

Epcon Industrial Systems

FIGURE 5. Direct-fired oxidizers may be the preferred emission-control solution when there is a very high VOC or hydrocarbon load, as well as fluctuating operating conditions

areas of the plant to alleviate the cost of additional equipment and overall fuel consumption.

Automation and software

When it comes to compliance, automation and software can provide much needed assistance to processors looking to ensure tighter control and faster, more accurate reporting.

"One of the factors that has driven the growth of automation is that it can help with environmental compliance and reporting," explains Lee Swindler, program manager with Maverick Technologies (Columbia, Ohio; www.mavtechglobal.com). "Automating the process instead of relying on human operators not only makes the plant run more profitably and reliably, but it also allows it to run with fewer emissions. It can also be used to help document and prove that the plant is in compliance and can measure actual emission levels and make a record, which can be used to provide regulatory agencies with the necessary information in a very timely manner."

One of the most important areas automation expertise can help is in the timely detection and reporting of emissions events, notes Swindler. "A lot of the compliance requirements involve being disciplined around how you monitor and report an event in which an emission limit has been exceeded. Typically this is a very lengthy manual process for many plants, which is problematic because there are often time limits associated with how quickly such events are acted upon and reported. A more automated reporting process can help alleviate this challenge, and is one of the areas where we see a lot of potential and promise."

Philip Black, environmental practice lead, with Wood Group Mustang (Houston; www.mustangeng.com) agrees that time is of the essence. Penalties, he adds, can become costly if a problem goes unnoticed for a significant period. "If you're required to maintain compliance on an hourly basis, but your environmental management system only processes data once a day, you may not have known there was an event until the next day. This means that you could have been out of compliance for 24 h, which could result in significant fines," says Black.

In addition, as technology increased and regulations tightened, processors began using continuous monitoring systems to analyze samples in realtime and provide values at a very high frequency. "Not only do the environmental agencies require processors to report all these data, but they often require a tremendous amount of quality assurance on the instruments themselves," he says. This means, according to Black, that processors must certify that not only are their emissions below a certain limit, but also that the many instruments monitoring the emissions are operating correctly nearly 100% of the time. "These data and associated quality assurance documentation must be reported together, in a timely manner," notes Black. He says that over the years, many processors have developed spreadsheets or other tools that require time-consuming manual work to handle this arduous reporting task.

"However," he continues. "There are software solutions that handle all the environmental calculations, quality assurance and validations in realtime, so that operators always know the current status and can be assured that the process is in compliance at any given time."

To this end, Wood Group Mustang offers ENVision, a software suite that provides a realtime flow of information and notifications of potential issues, allowing proactive responses to prevent non-compliance. The system brings transparency to the calculation process and lowers the cost of compliance by automating the data gathering and reporting. The software integrates with enterprise resource planning (ERP) software and environmental management information systems (EMIS) to automate additional reporting requirements, as well.

"One of the factors that has driven the growth of automation is that it can help with environmental compliance and reporting."

Lee Swindler, Maverick Technologies

Software may also be used to help processors reach compliance earlier in the design process. For example, aspenONE from AspenTech (Bedford, Mass.; www.aspentech.com) can be used to model, track and reduce emissions more effectively and earlier on in the design process. "Companies could achieve emissions reductions of up to 40% through improvements in operations and maintenance, investments in energy-efficiency measures at the equipment and process levels and the use of software tools to model and manage their operations," says a spokesperson for AspenTech.

The simulation modeling functionality in aspenONE Engineering helps process manufacturers by making it easier to comply with global health, safety and environment policies and regulations. The greenhouse-gas (GHG) calculation capabilities within AspenHYSIS and Aspen Plus give processors an automated solution that accurately determines GHG emissions for simulated processes. The new functionality calculates equivalent greenhouse-gas emissions (GHG) from direct and indirect sources, such as energy consumption and chemical processes, and reports on those emissions to support GHG reporting and compliance. ■

Joy LePree

Pipes, tubes and fittings

Thomas & Betts

Handle-Tech

New Age Industries

These fittings are designed to reduce strain, ease installation

Kopex-Ex ISR strain-relief fittings (photo) are designed to secure tray cables, portable cords and other unarmored cables in a wide array of industrial applications. They are IEC-Ex-, ATEX-, CSA- and UL-certified. These fittings feature an internal clamping mechanism that reduces the need for additional external clamping, thereby reducing installation time and cost, says the company. This design enables the industrial strain-relief fittings to comply fully with pullout requirements specified by the International Electrotechnical Commission (IEC), without the need for external clamping where the cables exit the enclosure. The design also ensures that pulling and twisting will not affect the terminations. — *Thomas & Betts Corp., a member of the ABB Group, Memphis, Tenn.*

www.tnb.com

This standalone hose handle reduces common injuries

This sturdy, removable handle (photo) can be locked onto a hose or pipe, allowing personnel to easily move heavy segments of piping or hoses from a natural, upright position. This device helps to reduce the risk of hand injuries, back injuries, slips and falls, hose decoupling and other accidents. Constructed from long-glass-fiber-reinforced nylon, the portable handle can be used in a variety of industrial environments, and it can be engaged and disengaged from the pipe or hose using one smooth motion, says the company. The device has a safe lifting capacity of 400 lb, and a breaking point of 1,125 lb. — *Handle-Tech Ltd., Edmonton, Alta.*

www.handle-tech.com

Conductive and anti-static materials provide benefits

This company offers a broad range of structural thermoplastic elastomers, compounding and custom-engineering expertise, to support the manufacture of pipes, hoses, tubing and fittings that are able to meet the most exacting engineering standards. Its extrudable, conductive compounds (available in a range of elastomers and rigid base polymers) provide high-electrical conductivity and electrostatic discharge (ESD) protection (thereby dissipating charges before they are able to reach potentially dangerous levels). These compounds can be used in the manufacture of vacuum hose, conductive pipe, ESD tubing, and fittings that must have consistent, high electrical conductivity. This is achieved by uniform carbon black dispersion, even in thin extrusions, says the company. — *RTP Co., Winona, Minn.*

www.rtpcompany.com

Antimicrobial tubing inhibits bacterial growth

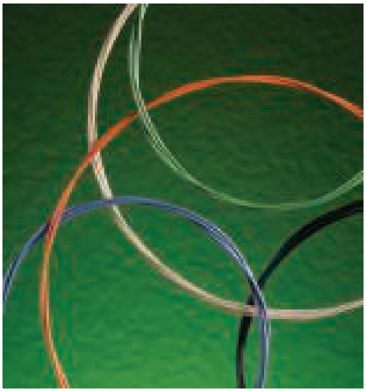
The Clearflo Ag-47 Antimicrobial PVC Tubing (photo) inhibits bacterial growth to protect transferred fluids from contamination, odor and the threat of transmission of illnesses caused by more than 50 different types of bacteria, including *E. coli, Listeria, Salmonella, Pseudomonas* and others (tested in accordance with ISO 22196:2011). The tubing is designed for use in fluid-transfer applications involving food, beer and alcoholic beverages, dairy products, and for the transfer of clean liquids that are required in medical, laboratory, water and wastewater environments. Silver ion additives are used throughout the clear, flexible PVC tubing — not just on the interior surfaces, as is the case with some competing products, says the company. This tubing is listed by the National Sanitation Foundation (NSF-51) for use in food-handling equipment. The tubing does not contain latex, animal-derived components or phthalates. The tubing handles temperatures between –40 and 52°C, and is stocked in ten sizes, ranging from 3/16 to 1/2 in. inner dia. — *New Age Industries, Southampton, Pa.*

www.newageindustries.com

Note: For more information, circle the 3-digit number on p. 74, or use the website designation.

Parker Hannifin

Milliken Infrastructure Solutions



Valco Instruments

Belzona Polymerics

Improved tube connector ensures easy assembly

These tube connections feature a flared-cone technology design that allows for rapid installation with minimal training (compared to traditional cone-and-thread tube connections). The new connector design (photo) combines the makeup and installation simplicity of compression-style connections with the strength of cone-and-thread connections, and provides more features and higher pressure capabilities than similar technologies, according to the company. The design prevents tube ejection and provides a redundant, second seal for enhanced reliability. Designed for working pressures as high as 22,500 psi (1,550 bars), the FCC technology advances the performance of compression-style tube connections, providing users with a simple and reliable means of speeding the assembly of instrument tubing systems for use in higher-pressure applications. — *Parker Hannifin, Cleveland, Ohio*
www.parker.com

Simple system minimizes crevice-related corrosion

This company's patented Pipe Sock technology provides structural pipe reinforcement, leak repair and corrosion prevention (photo). Pipe Sock is a fiber-reinforced polymer that helps to eliminate corrosion problems in crevices on the exterior surfaces of piping and tanks. It offers an improvement to traditional epoxy solutions, which tend to crack at the interfacial boundary, thereby creating additional hidden opportunities for crevice corrosion opportunities, says the company. Pipe Sock consists of a pre-formed, size-specific fiberglass wear pad and a specially formulated adhesive system, thereby ensuring good integrity between the Pipe Sock and the pipe and eliminating penetration and condensation cavities. The material can accommodate temperatures up to 250°F, and installation requires no special tools. — *Milliken Infrastructure Solutions LLC, Spartanburg, S.C.*
www.infrastructure.milliken.com

A range of PEEK tubing options to meet your needs

This company's polyether ether ketone (PEEK) tubing (photo) is available in a variety of options, including natural, solid color-coded, dual-layer color-coded, striped and dashed-strip coded. The dual-layer color-coded PEEK tubing has an integrally bonded inner layer of natural PEEK, to eliminate the risk that a sample stream might be contaminated by pigments used to color-code the tubing. A range of outer-diameter sizes are available (between 360 microns and 1/8 in.) and inner diameters are available as low as 0.02 in. diameter with different colorants added to readily identify and recognize the selected tubing according to its inner diameter. — *Valco Instruments Co., Houston*
www.vici.com

Repair pipes and tanks with this composite technology

The Belzona SuperWrap II pipe-wrap repair system (photo) combines a cold-curing, fluid-grade epoxy resin and a hybrid reinforcement sheet consisting of glass and carbon fibers.The glass fibers provide sheet flexibility, while the carbon fibers give the applied composite the strength needed to withstand high pressures and mechanical loading. Two different resins are available (to accommodate different service temperatures). This product has recently undergone additional reformulation enhancements, to build upon and expand the performance of the predecessor product. The composite-repair method restores strength to weakened or perforated metallic substrates without the need for hot work or lengthy downtime, says the company. This product has achieved compliance with a variety of key industry standards, including ISO 24817 (Composite Repairs for Pipework) and ASME PCC-2 Article 4.1 (Non-metallic Composite Repair Systems for High-Risk Applications). It is particularly well-suited for complex geometries that include bends, straights and tees, and can also be applied as a patch repair to large pipes (over 600-mm dia.) and tank walls. It uses a simple, two-part epoxy resin system and provides a 20-year design life (in accordance with ISO 24817). — *Belzona Polymerics Ltd., Harrogate, U.K.*
www.belzona.com

Monitor fluid leakage where visual inspection is not possible

Several leak-detection systems are

available to monitor complex piping installations. The TT3000 sensor cable is designed to detect wastewater, acids, bases and any other liquid that is conductive in double-containment piping systems. The TT5000 Fuel Sensor Cable is a leak-detection sensor that is designed to monitor the soil under and around pipes and tanks carrying fuels. It detects fuel but ignores water. Branch connectors simplify the tracing of complex manifolds and hydrant systems, and every meter of cable has a unique "address" so that leaks are detected and the locations are reported to an accuracy of ±1 m along the length of a pipeine or beneath a tank floor. This allows repairs to be accurately directed, says the manufacturer. — *Tyco Thermal Controls, Redwood City, Calif.*
www.tracetek.com

Specialty tubing options are available in many metals

This company offers a diverse array of tubing products, in a variety of metals, grades and sizes. Its offerings include seamless-steel tubing, steel tubing with a chrome-plated inner surface, aluminum, brass, carbon and stainless steel tubing in many grades, steel tubes with chrome plating on the outer surface and more. Most tubing is available in the honed, skived and roller-burnished, or unhoned condition. Customization is available. — *Scot Industries, Auburn, Ind.*
www.scotindustries.com

Double-containment piping uses three leak-detection tools

This company recently launched a new double-containment piping system that features three leak-detection systems — the 918Q Alarm Box, the PAL-AT Continuous Cable System, and the Low Point Leak Detection System. The piping system is designed for wastewater treatment plants and buried applications. In the event of a leak, these detection systems are able to help determine where the leak is located, and translate that information to plant personnel in a timely manner. The 918Q Alarm Box handles up to four sensor signals and features audible and visual alarm indicators. The device emits a 90-dB alarm from four feet away and uses standard lithium bateries (low-battery visual indication is included). The microprocessor-based PAL-AT offers multi-sensing and remote monitoring of up to four separate sensing zones, each with up to 7,500 ft of sensor cable, and is capable of locating multiple leak points, as well as growing leaks. The customizable Low Point Leak Detection System uses 12 discrete inputs that allow the specific location of the leak in the piping to be found.— *GF Piping Systems, Irvine, Calif.*
www.gfps.com

Steels and alloys withstand aggressive environments

This company offer a full range of stainless steels and alloys (including duplex and super-duplex grades) that can provide reliable corrosion

resistance in high-temperature, high-chloride-concentration environments. The alloys have been developed to combine high strength in the solution-annealed condition, with localized corrosion-resistance properties that are said to be better than super-duplex grades. The hyper-duplex grade Sandvik SAF 3207 alloy is especially well-suited for use in tubing, raw-seawater injection systems, aerated seawater environments, downhole applications in oil-and-gas recovery, umbilicals and other applications that require high strength and relatively thin walls combined with improved resistance to chloride-induced corrosion and cracking and high operating temperatures.— *Sandvik Materials, Sandviken, Sweden*
www.sandvik.com

Composite fluoropolyers handle challenging situations

AGC Chemicals Americas

Fluon ETFE is a melt-processable copolymer of tetrafluoroethylene and ethylene that is designed for a wide variety of challenging applications, including tubing and pipe, wire and cable coatings, semiconductor and electronic components, valves, fittings, and pump housings (photo). To optimize chemical resistance and engineering performance, three Fluon ETFE compounds are reinforced with proprietary conductive, strengthening and reinforcing fillers and fibers, which allow itl to tolerate extreme temperatures, pressures, harsh chemicals and volatile weather conditions, and to remain flexible and withstand cracking during manufacturing, spooling and use.— *AGC Chemicals Americas Inc., Exton, Pa.*
www.agcchem.com

Firm offers many piping options and pipeline services

This company offers a range of products and services, including pre-insulated piping systems for direct heating and cooling, and pipe-in-pipe containment systems to ensure the proper management of hazardous fluids, subsea oil-and-gas pipelines and equipment, aboveground and underground insulated piping systems for industial applications, leak-detection and a variety of detection options. The company also provides a variety of leak-detection services, including infrared leak-detection surveys (which can identify areas of high thermal loss that indicate wet insulation that has resulted from conduit or pipe leaks), tracer gas surveys to pinpoint leaks in steel conduit systems, ultrasonic testing to measure pipe wall thickness, and more. — *Perma-Pipe, Inc. Niles, Ill.*
www.permapipe.com ■

Suzanne Shelley

Use this valve in high-pressure calibrations

This company's new Trunnion-style block-and-bleed ball valve (photo) is intended for calibration applications up to 15,000 psi. This full-port, quarter-turn double ball valve is designed to provide double positive isolation, and is appropriate for high-pressure hydraulic and pneumatic systems used for pressure monitoring and testing, chemical injection and drain-line isolation. Featuring 316 stainless-steel construction, Viton O-rings and polyetheretherketone (PEEK) ball seats, the valve is suitable for severe-service applications. The valve is available with orifice sizes of 0.203, 0.250, 0.313 and 0.375 in. — *High Pressure Equipment Co., Erie, Pa.*
www.highpressure.com

Powder transfer systems for a wide density range

This company's powder transfer systems (photo) incorporates stall-free air valving and a new air-induction system that boosts efficiency and eliminates powder pack-out at startup, allowing for the transfer of powders ranging in density from 5 to 50 lb/ft^3. The air-induction system also increases air velocity for optimum powder aeration and diffusion, says the manufacturer. The four-way air-efficiency valve can control the amount of air (or other inert gases) required for operation. The system is designed for portability so that it can be moved from site to site. The built-in delay timer ensures proper fluidization of the powder before startup. Directly controlled by the delay timer, the main startup valve supplies air pressure directly to the pump's major air valve. — *ARO Fluid Management, Bryan, Ohio*
www.arozone.com

A predictive control solution designed for grinding mills

SmartMill is a new predictive-control solution for continuous control of individual grinding mills. Embedded within a variable-speed drive, SmartMill utilizes realtime data to control feedrate, rotation speed, mill load and more. The speed is varied according to an advanced control concept that keeps the mill's solids feed as high as possible, while monitoring signals, including power consumption, motor torque, bearing pressure and mill speed, allowing for automatic selection of optimal setpoints, says the manufacturer. For inputs, SmartMill uses power, torque and load, which are used to predict future mill behavior. The outputs can take into account several mill variables, such as feedrate, mill rotation speed, ore hardness and purity, total load and water addition rate. SmartMill provides stability to individual mills without the need for additional controllers or sensors. — *ABB, Zurich, Switzerland*
www.abb.com

A corrosion-resistant, lightweight scale

The Model 3001-3006TM Ton Cylinder Scale (photo) has been redesigned for easier installation and improved corrosion resistance. Fabricated from high-grade plate steel, the new scale is lighter and has a smaller footprint than previous models, says the company. The new design also features improved protection of the hermetically sealed load cell and scale electronics. The steel crossbar running along the front of the scale base now includes a cover plate to protect the load cell from dust, dirt and dripping liquids, such as condensate. The new Model 3001-3006 Ton Cylinder Scale has a gross capacity of up to 4,000 lb, with weighing accuracy to ±0.5% of capacity. — *Scaletron Industries, Ltd., Plumsteadville, Pa.*
www.scaletronscales.com

These pressure transmitters address issues with drift

The 4400 and 4600 hammer-union pressure transmitters (photo) are designed for use in hazardous areas, where pressures can reach 20,000 psi. Available with intrinsically safe or explosion-proof approvals, these transmitters have been laboratory-tested for shock and vibration resistance, and are field-tested for the most extreme ambient conditions. Employing a thick Inconel 718 diaphragm and silicon strain gages, these transmitters experience less drift, even in longterm service, says the company. A cage around the pressure transmitter is designed to protect the sensor

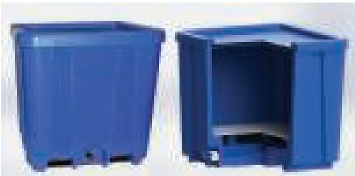

High Pressure Equipment


ARO Fluid Management


Scaletron Industries


American Sensor Technologies

Camfil Air Pollution Control (APC)



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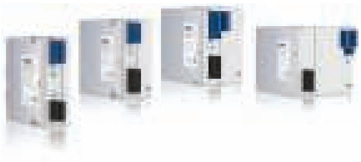


WAGO

and mating connector, allowing for proper drainage in flooding situations. — *American Sensor Technologies, Inc., Mt. Olive, N.J.*
www.astsensors.com

A robust flowmeter designed for superheated steam

The Optisonic 8300 is a two-beam ultrasonic flowmeter for superheated steam that is capable of handling high flowrates with 1% measuring accuracy. Built for longterm use, the flowmeter has no exposed cables or sensitive elements, and features a full-bore flow sensor with no moving parts or obstructions. According to the manufacturer, the meter can maintain its measuring accuracy without maintenance or subsequent calibration for up to 20 years. The Optisonic 8300 is rated for pressures up to 200 bars and temperatures up to 540°C, with higher-rated units available on request. Temperature and pressure sensors connected to the device provide the integrated flow computer with data to calculate steam mass flow, eliminating the need for an additional computer. — *Krohne, Inc., Peabody, Mass.*
www.us.krohne.co

This modular steam-trapping station reduces leakage

The STS17.2 steam-trapping station is a complete assembly comprised of an isolation valve, a steam-trap connector with a strainer and a check valve. The station's modular body eliminates nearly all potential leak paths caused by multiple screwed connections that conventional steam-trapping stations and on-site fabricated installations typically include, says the manufacturer. The ability to integrate steam-trap monitors allows for quick recognition of trap failures, and stainless-steel components enable a longterm, low-maintenance service life. — *Spirax Sarco, Inc., Blythewood, S.C.*
www.spiraxsarco.com

This dust collector requires just one filter cartridge

The Quad Pulse Package PX dust collector (photo) is a compact unit designed for pharmaceutical, chemical and other processes that produce hazardous dusts in high concentrations. The collector has a cleanable filter system that facilitates continuous manufacturing processes and eliminates frequent filter replacements. The unit can be positioned on the production floor and constructed to provide explosion protection in accordance with NFPA standards. If located indoors, there is no need for additional explosion-safety devices. Thanks to a segmented cleaning process performed during operation, the Quad Pulse Package requires a single primary filter cartridge. The high-efficiency primary pleated filter comes in a conductive (anti-static) nanofiber or polytetrafluoroethylene (PTFE) media. — *Camfil Air Pollution Control (APC), Jonesboro, Ark.*
www.camfilapc.com

A single-unit separation system for recovering liquids and solids

The MRS-30 model material recovery station (photo) is designed to automatically separate liquids from solids within a single, self-contained unit that features a proprietary screening panel set inside a leak-proof, bulk plastic container to screen out and capture solid particles and allow liquids to safely pass through and accumulate in the container bottom. When filled to its 30-gal capacity, the MRS-30 may be drained to allow the liquids to be reprocessed and reused onsite, while the solids may be sold as scrap. Suitable as a standalone system or integrated within existing fluid-recycling systems, the MRS-30 effectively separates and collects metal waste chips, ceramics, plastics, rubber and other materials from spent cutting fluids and other liquids. — *MODRoto, Inc., Madison, Ind.*
www.modroto.com

A versatile family of power-supply devices

This company's Epistron Classic power-supply devices (photo) are available in one-, two- and three-phase versions. All models in the Epistron Classic family have identical housing profiles, and wide input and voltage ranges, making them suitable for many types of applications. The ambient temperature range for the Epistron Class family is –25 to 70°C, with a high transient-protection level of up to 4 kV. Enhanced output protection for standard circuit breakers is integrated into the devices. — *WAGO Corp., Germantown, Wis.*
www.wago.us

This boiler-treatment technology is now FDA approved

This company's Solus AP boiler-treatment solution has recently received approval from the U.S. Food and Drug Admin. (FDA) for use across regulated industries where steam comes into contact with food products. Solus AP is an all-polymer technology in a stable, liquid formulation designed to meet the deposit-control needs of low- to intermediate-pressure steam boilers (up to 900 psig). By improving the control of iron and hardness deposits, steam boilers that have been treated with Solus AP (photo) help plant operators achieve design fuel efficiency, as well as higher levels of safety and reliability by preventing deposit-related failures, according to the manufacturer. With the recent FDA approval, the use of Solus AP can be expanded into food and beverage, pharmaceutical and healthcare applications. — *GE Power & Water, Schenectady, N.Y.*

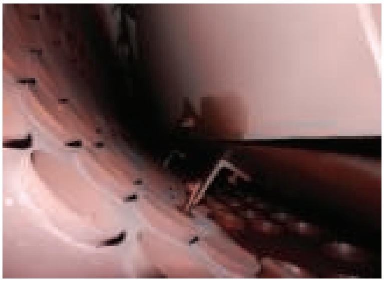
www.gepower.com

Use this high-precision amplifier in tough production areas

The DMP41 digital precision measuring instrument (photo) features an accuracy class of 0.0005 (5 ppm), and is said to be the world's most precise amplifier for strain-gauge-based sensor measurements. Unlike other high-precision instruments that are limited for use only in controlled laboratory conditions, the DMP41 is available in a 19-in. rack-mount enclosure that is constructed to enable use in environments with demanding conditions. Manufacturers of strain-gauge-based sensors, such as force, torque and pressure transducers, load cells and flowrate sensors, can use the DMP41 to precisely calibrate and adjust their sensors during production. A background calibration feature allows the instrument to make measurements even while internal calibration of internal measurement channels is in progress. This increases test-system throughput. — *HBM, Inc., Marlborough, Mass.*

www.hbm.com

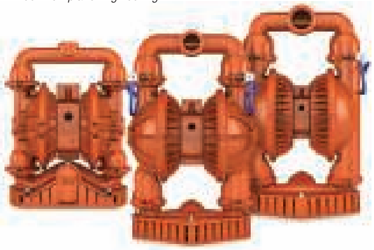
GE Power & Water



HBM

Omega Engineering


Acromag

Wilden Pump and Engineering



SAWA Pumpentechnik

A handheld anemometer with environmental readings

The Omega HHF-312 anemometer (photo) measures ambient temperature, humidity, barometric pressure, wind speed and direction all in one multi-functional, lightweight, handheld meter. The HHF-312 calculates windchill index, as well as dewpoint and wet-bulb temperatures, and features a backlit LCD with dual readouts and compass. The tripod fitting makes this anemometer ideal for outdoor environmental studies, and operations in cold, windy environments. Application examples include environmental studies and HVAC (heating, ventilation, air conditioning) troubleshooting. — *Omega Engineering, Inc., Stamford, Conn.*

www.omega.com

New industrial Ethernet switches and media converter

The LNX Series of unmanaged rugged industrial Ethernet switches and IMC media converters (photo) are now available from this company. Select from a variety of models with up to eight ports for copper or fiber cabling on fast Ethernet or Gigabit networks. Most units support extended –40 to 75°C operation and include a rugged IP30 aluminum enclosure that resists shock, vibration and free-fall impacts. These industrial Ethernet switches and media converters carry UL/cUL Class 1 Div. 2 certifications. — *Acromag, Wixom, Mich.*

www.acromag.com

This membrane bioreactor requires less air

The Pulsion MBR membrane bioreactor pulses a large bubble through a chambered fiber bundle, creating an efficient pumping action that results in lower air and aeration energy requirements than traditional air-scour methods, says the manufacturer. Improved recirculation within the membrane module boosts achievable fluxes. An increase in packing density allows the overall system footprint to be significantly reduced. A reduced air flowrate applied to the membranes on a continuous basis reduces the size of the air-delivery equipment by an estimated 50%. — *Koch Membrane Systems, Wilmington, Mass.*

www.kochmembranes.com

This AODD is equipped with an efficient air-distribution system

Stallion Original Metal air-operated double-diaphragm (AODD) pump models (photo) are powered by the energy-efficient Pro-Flo Shift Air Distribution System (ADS). The Pro-Flo Shift incorporates an air-control spool that automatically restricts the amount of air going into the pump during the latter part of each stroke, which eliminates over-filling of the air chamber and results in reduced air consumption. By optimizing air consumption, the Pro-Flo Shift lowers energy and operating costs, achieving up to 60% savings over competitive AODD pump technologies, says the company. The new Stallion Series pumps are available in three sizes. Flowrates range from 307 to 764 L/min. — *Wilden Pump and Engineering, Grand Terrace, Calif.*

www.wildenpump.com

Expanded filtration-system range enables easier scaling

Two new sizes of this company's Beco Integra Plate filtration system are now available: a small 7.9-in. and larger 39.3-in size, meaning that users in the fine-chemical and pharmaceutical industries can scale their systems from laboratory applications to higher batch volumes in commercial manufacturing processes. The system is a hermetically enclosed plate-and-frame filter that enables users to increase process efficiencies in demanding filtration applications. The range has been expanded and is now available in five sizes, and delivers a filter area from 0.6 up to 1,227 ft^2. — *Eaton, Tinton Falls, N.J.*

www.eaton.com/filtration

Stainless-steel pumps for the beverage and distilling industries

The stainless-steel hybrid pump LES (photo) is said to be an alternative to side-channel pumps. The pump features a specially designed pump cover with an integrated recirculation system, as well as an inducer, which allows the pump to be used in self-priming applications. The pump has a hygienic design, based on European Hygienic Engineering and Design Group (EHEDG) guidelines, making it suitable for use in the food-and-beverage, pharmaceutical, cosmet-

ics and chemical industries. Optional versions are available with ATEX approval (Zones 1, 2 and 21, 22); pharmaceutical-specific design; magnetic coupling; and more. The pumps have a maximum flowrate of 150 m^3/h, and delivery heads of up to 60 m, and they handle liquids with viscosity up to 500 mPa-s. — *SAWA Pumpentechnik AG, Degersheim, Switzerland*
www.sawa.ch

These new, miniature AODPs are ATEX certified

Both the Model MID and CU15 (photo) miniature air-operated diaphragm pumps (AODPs) are ATEX certified for potentially explosive atmospheres, making them suitable for environmental and process-emissions monitoring. The standard version of both pumps is ATEX classified II for Zone 2, and the optional Conduct versions are ATEX classified II for Zone 1. The pumps facilitate transfer of liquids with very high viscosity, and are available with polypropylene (PP) or ethylene chlorotrifluoroethylene (ECTFE) pump bodies. The MID provides flowrates up to 5 L/min at pressures of up to 99.7 psi, and has a maximum operating temperature of 60°C. The CU15 provides flowrates to 17 L/min, with maximum operating temperatures of 60°C for PP models and 95°C for ECTFE models. — *Clark Solutions, Hudson, Mass.*
www.clarksol.com

Clark Solutions

This auto-start sterilizer requires no pre-heating

The SteriMax Smart sterilizer uses specifically focused infrared light (IR) to sterilize inoculating loops at temperatures of 750 to 1,000°C in 5–10 s without any preheating. IR sensor technology enables an auto-start functionality. The device's annealing tube is constructed of specialty quartz glass, and is designed for simple cleaning. The housing is constructed of stainless steel and safety glass, and is designed to be cool to the touch. — *WLD-TEC GmbH, Göttingen, Germany*
www.wld-tec.com ■


WLD-TEC

Mary Page Bailey and Gerald Ondrey

Circle 24 on p. 74 or go to adlinks.chemengonline.com/56203-24

Facts At Your Fingertips

Design and Operating Principles for Bioprocesses

Department Editor: Scott Jenkins

The application of biotechnology to the chemical process industries (CPI) has grown significantly in the past decade and now offers viable pathways to manufacture a range of high-volume chemicals, many of which can serve as drop-in replacements for traditional petroleum-derived chemicals. Bio-based processes have some unique characteristics compared to traditional chemical processes, and that, when combined, have the potential to lower capital and operating expenses per ton of capacity, while enabling the use of alternative feedstocks. Bioprocesses can often deliver more sustainability while meeting existing quality criteria. This column provides an overview of the differences between bio-based and traditional processes.

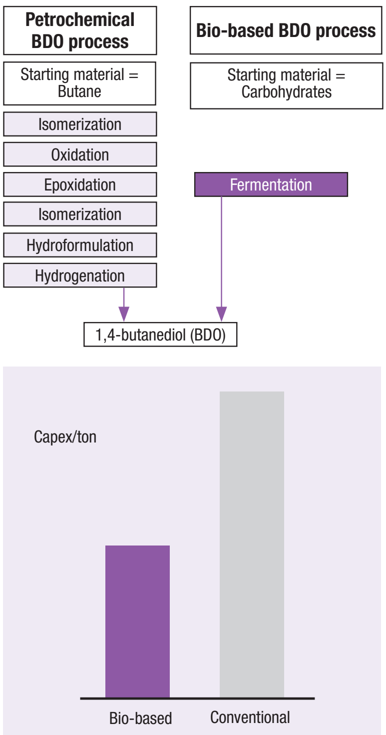


FIGURE 1: A petrochemical-based route to butanediol is compared to Genomatica's bio-based BDO process. Fewer unit operations, fewer byproducts and gentler operating conditions can result in lower capital expenditures (capex) per ton of capacity for bio-based processes. This can enable economical deployment of smaller plants

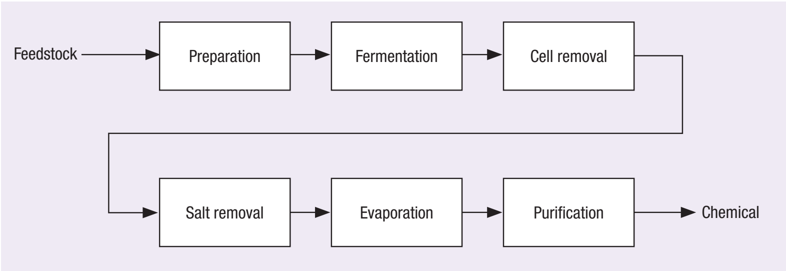


FIGURE 2: This block flow diagram shows the sample operations for a generic bio-based process

Simple plant design

Biotechnology has the ability to engineer microorganisms so a single unit operation (fermentation) can replace multiple chemical reaction steps and efficiently convert feedstock into desired molecules, such as butadiene, caprolactam or butanediol. Bioprocess feedstocks can include various carbohydrates or cellulosic biomass, as well as traditional petrochemical feedstocks, including C1 sources.

Process differences

The following items represent some potential advantages that can be realized with bio-based processes.

Fewer unit operations. Fermentation by microorganisms means that a single unit operation can, in some cases, replace complex reaction sequences in conventional processes.

Fewer byproducts. Biological systems tend to be very selective, meaning that organisms can produce exactly the chemical of interest, rather than a mixture of hydrocarbons. This can increase overall process yield, reduce the number and volume of byproducts and thereby decrease the associated separation costs. Selectivity can sometimes even improve final product quality.

Gentler operating conditions. Fermentations run at near-ambient temperatures and pressures, so plant equipment is less costly.

Differentiated products. Chemicals made with bio-based processes, especially those made from renewable feedstocks, typically have a smaller environmental footprint, allowing producers to better meet increasing customer demands for sustainable products, and often increasingly stringent pollution regulations.

New operating procedures. Bio-based processes often require different operating know-how than traditional petrochemical processes. Examples of this specialized expertise include the need for aseptic operation of the fermentation, process control of a biological system, different separation and purification operations, process chemistry in aqueous streams, and new options for process integration and energy minimization. Even firms with deep process engineering and petrochemical-plant operating experience will benefit from working with experts in designing and operating integrated end-to-end bioprocesses.

Biotechnology: a useful tool

Going forward, biotechnology will increasingly become a useful component of the toolkit and production portfolio of CPI companies. The increased use of biotechnology will be driven by its ability to provide added flexibility and cost benefits. Fully realizing the potential of a bioprocess to reduce capital and operating costs often requires changes in the way plants are designed and operated. These changes can be readily addressed by collaborating with bioprocess experts. ■

Editor's note: This column was provided by Genomatica Inc. (San Diego, Calif.; www.genomatica.com), a leading innovator in biotechnology for the chemical industry. The author is Michael Japs, director of commercial technology development for Genomatica. The company is adept at harnessing biotechnology to develop new, advantaged processes for major chemicals, as well as custom solutions for its partners. The firm is a recipient of the 2013 Kirkpatrick Award for Chemical Engineering Achievement. Japs can be reached at mjaps@genomatica.com.

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Ethylene Production via Cracking of Ethane-Propane

By Intratec Solutions

Ethylene is a critical building block for the petrochemical industry, and is among the most produced organic compounds. It is usually produced in steam-cracking units from a range of petroleum-based feedstocks, such as naphtha, and is used in the manufacture of several major derivatives.

The process

The process shown in Figure 1 is a steam-cracking process for ethylene production from an ethane-propane mixture. The process can be divided into three main parts: cracking and quenching; compression and drying; and separation.

Cracking and quenching. Initially, an ethane-propane mixture is fed to furnaces in which, under high-severity conditions, it is cracked, forming ethylene, propylene and other byproducts. The furnace outlet stream is subsequently fed to a water-based quench, to prevent further reactions and formation of undesirable byproducts.

From a decanter downstream from the quench tower, heavies, condensed dilution steam, tar and coke are removed. Cracked gas from the quench is then directed to compression and separation.

Compression and drying. The compression of the cracked gas is performed across five stages. After the third stage of compression, carbon dioxide and sulfur are removed from the cracked gas by caustic soda and water washes in a caustic scrubber. The compressed cracked gas is cooled and subsequently dried by molecular sieves that remove most of the water.

Separation. The dried cracked gas is fed to a cold box for the removal of hydrogen and light hydrocarbons, while minimizing ethylene losses.

At this point, condensates from the chilling train are fed to a series of separation columns. In the first column (demethanizer), methane is obtained from the top and further used in the cold box, while the bottom stream is fed to a second column (deethanizer).

The top of the deethanizer, composed primarily of ethylene and ethane, is fed to an acetylene converter and then fractionated in the C2-splitter. In this column, lights are removed from the overheads and recycled to the compression system, while polymer-grade (PG) ethylene is drawn from the column as a side stream. Ethane, from C2-splitter bottoms, is recycled to the cracking furnaces.

The deethanizer bottom stream is fed to a depropanizer, which distills C3 components in the overheads. This overhead stream is catalytically hydrotreated for methyl acetylene and propadiene removal, and then fed to the C3-splitter. In this column, lights are removed from the overheads and recycled to the compressors, while polymer-grade (PG) propylene is drawn from the column as a side stream. Propane from C3-splitter bottoms is recycled to the cracking furnaces. A C4+ stream is obtained from the depropanizer bottoms.

Economic performance

An economic evaluation of the process was conducted based on data from the first quarter of 2015, considering a facility with a nominal capacity of 1,700,000 ton/yr of ethylene constructed on the U.S. Gulf Coast.

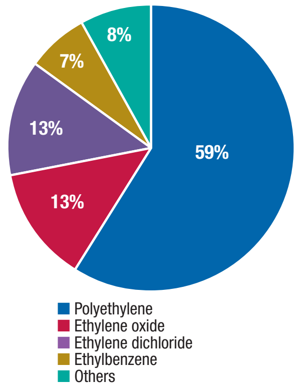


FIGURE 2. Ethylene is made into a host of products

Estimated capital expenses (total fixed investment, working capital and initial expenses) to construct the plant are about \$2.37 billion, while the operating expenses are estimated at about \$360 per ton of ethylene produced.

Global perspective

With a global nominal capacity of about 155 million ton/yr, ethylene is among the major petrochemicals produced worldwide. The major part of ethylene production is consumed in the manufacture of polyethylene, but ethylene is also applied in the production of ethylene oxide, ethylene dichloride and ethylbenzene (Figure 2). ■

Edited by Scott Jenkins

Editor's Note: The content for this column is supplied by Intratec Solutions LLC (Houston; www.intratec.us) and edited by Chemical Engineering. The analyses and models presented are prepared on the basis of publicly available and non-confidential information. The content represents the opinions of Intratec only. More information about the methodology for preparing analysis can be found, along with terms of use, at www.intratec.us/che.

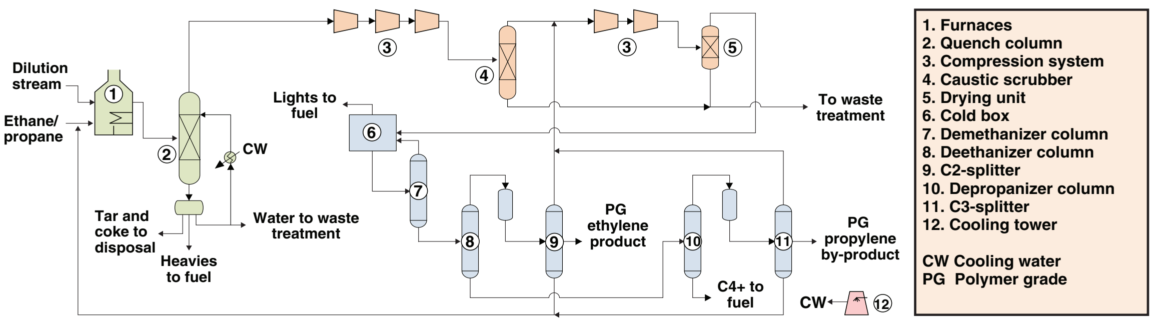
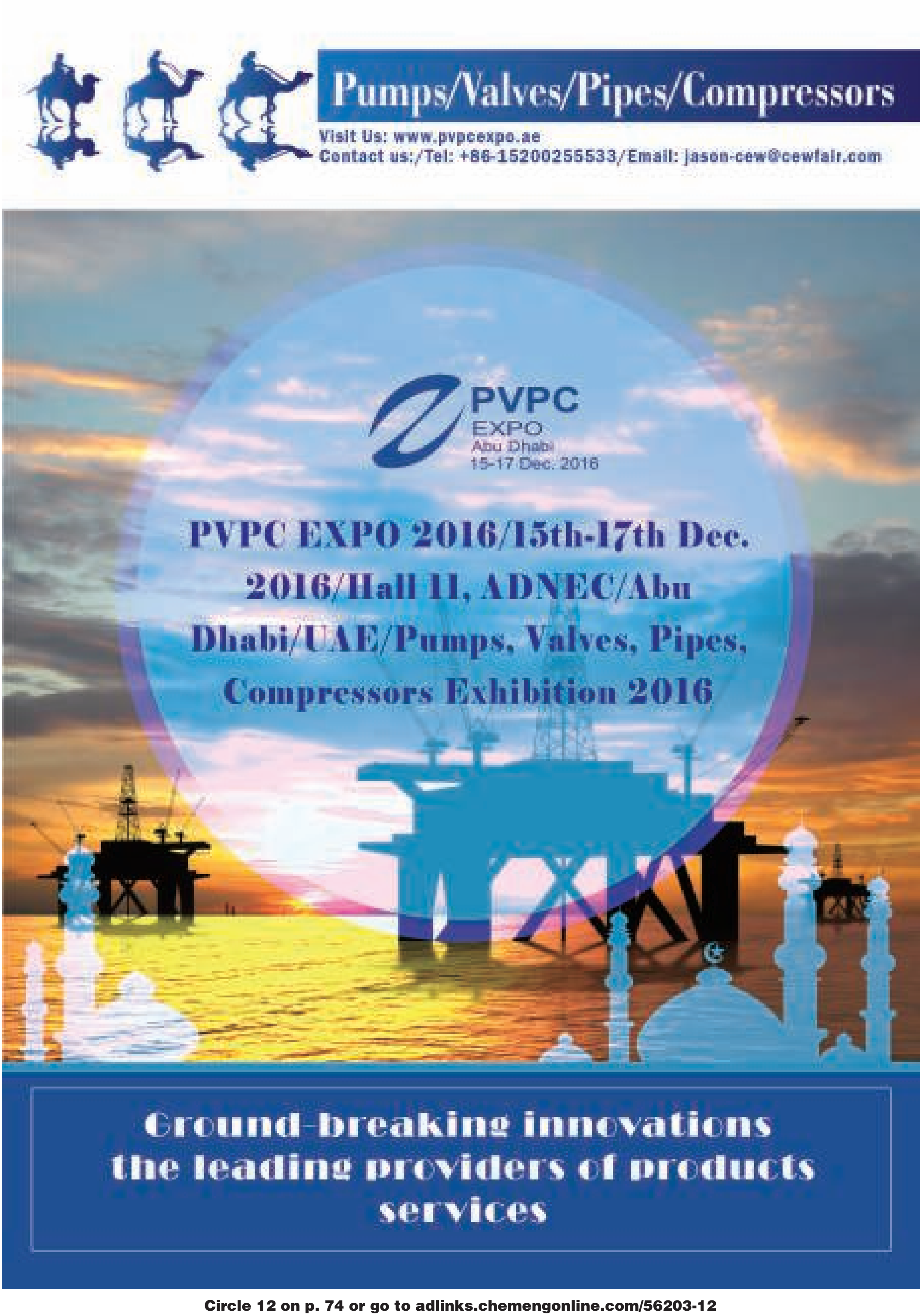


FIGURE 1. This process diagram shows an ethylene-production process via the cracking of an ethane-propane mixture



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Safety in Sulfuric Acid Storage Tanks

Commonly used in the CPI, sulfuric acid requires many special precautions to ensure its safe handling and storage

Koya Venkata Reddy
FACT Engineering and Design Org. (FEDO)

IN BRIEF

- CORROSION CONTROL
- INSPECTION
- INSTRUMENTATION
- SWITCHING OF TANK SERVICE
- TANKS IN SPENT-ACID SERVICE
- SECONDARY CONTAINMENT SYSTEMS
- PPE AND HSE
- VENTING REQUIREMENTS
- TRANSFER PUMPS
- HOT WORKS IN TANK FARMS
- PIPELINES, HOSES AND VALVES

FIGURE 1. Storage tanks in sulfuric acid serice require many special precautions to ensure safe operations and prevent accidental spills or ignitions

Sulfuric acid, sometimes called the "king of all chemicals," is widely used in the chemical process industries (CPI) for the manufacture of various fertilizers and other chemicals. Sulfuric acid (H_2SO_4) is typically stored and handled in steel storage tanks in tank farms (Figure 1) located at ports, sulfuric acid plants, fertilizer plants and so on. Numerous incidents involving explosions and spills in sulfuric acid storage tanks have been reported worldwide. All too often, a lack of understanding regarding the proper safety aspects required for handling and storing sulfuric acid leads to catastrophic accidents. These incidents can result in environmental pollution, as well as injuries and fatalities.

For example, in 2001 at a petroleum refinery in Delaware, a crew of contractors was repairing grating on a catwalk in a sulfuric acid storage-tank farm when a spark from their hot work ignited flammable vapors in one of the storage tanks. One of the acid storage tanks separated from its floor, instantaneously releasing its contents. Other tanks in the tank farm also released their contents. A fire burned for approximately 30 min, and sulfuric acid reached a nearby river, resulting in significant environmental damage. One worker was killed and eight were injured [*1*].

Such incidents draw attention to the vulnerability of sulfuric acid storage tanks to fires and explosions, in addition to accidental spillage. These occurrences can be avoided by understanding the various aspects of corrosion in storage tanks, inspection and venting requirements, spillage-containment systems, instrumentation, proper materials of construction, various governing codes and standards, guidelines for hot work and so on. This article describes various problems faced in sulfuric acid tanks and the efforts needed to mitigate them.

Corrosion control

Corrosion is one of the most prevalent issues in handling sulfuric acid. Two common corrosion mechanisms — hydrogen grooving and boundary-layer corrosion — are especially dangerous in sulfuric acid service because they lead to the formation of hydrogen gas (H_2), which is highly flammable, colorless, odorless and readily ignitable. It forms an explosive mixture with air and oxygen. The lower and upper explosive limits (LEL and UEL) of H_2 are 4% and 74.2%, respectively. This means that if the concentration of H_2 is between 4% and 74.2%, and if the gas mixture is ignited, it will lead to an explosion, causing potentially fatal harm and damage to assets. Hydrogen grooving and boundary-layer corrosion are detailed in the following sections.

Hydrogen grooving. Tanks for storing concentrated sulfuric acid typically are made of carbon steel. The acid reacts with iron (Fe) in the shell, forming a protective layer of ferrous sulfate ($FeSO_4$), while simultaneously releasing H_2, according to the following reaction:

$$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$$

At the inlet line, as the acid is flowing into the tank, H_2 bubbles float up and come into contact with the metal. The bubbles will scrape off the iron sulfate coating, exposing bare metal. This will form more iron sulfate and release more H_2 bubbles. Eventually, the formation of H_2 bubbles in the metal forms grooves or corroded portions and is called hydrogen grooving.

Boundary layer corrosion. In tank farms, a corrosive atmosphere also prevails, as sulfur dioxide vapors from the storage tanks can combine with moisture, forming sulfurous acid (H_2SO_3). This causes the tank roofs and other iron-containing materials in the vicinity to corrode.

In acid plants, the sump tanks of absorption towers contain acid analyzers that control the addition of dilute acid. If these analyzers malfunction, it can lead to an increase in the acid temperature. If high-temperature acid is transferred to carbon-steel storage tanks, corrosion will occur at a much faster rate.

The general rate of shell corrosion of storage tanks for concentrated sulfuric acid service is approximately 5 to 20 mils per year (0.005 to 0.020 in./yr) [*1*]. Anodic protection should be provided for the storage tanks to minimize the corrosion of the shell.

Inspection

Periodic thickness measurements of a tank's shell and roof should be carried out to ascertain whether the tank is fit for service. According to the recommendations of the National Association of Corrosion Engineers' (NACE; Houston; www.nace.org) Standard RP 0294-94, an internal inspection of sulfuric acid tanks is to occur every five years, and an external in-service inspection is to be carried out every two years [*2*]. Similarly, the American Petroleum Institute (API) Standard 653 requires the evaluation of flaws, deterioration or other conditions that might affect the performance of a tank and the determination of its suitability for the intended service [*3*].

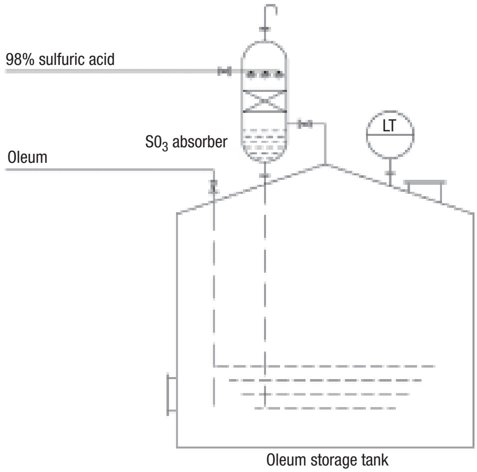

FIGURE 2. Oleum, a product of sulfuric acid plants, creates safety issues in storage tanks due to the presence of sulfur trioxide (SO_3) fumes

The periodic inspections should be performed more frequently as tanks become older. Per NACE RP 0294-94, inspection frequencies may be decided on the basis of operating conditions, experience, inspection results, fitness-for-service evaluations and risk analysis [*2*]. Furthermore, risk-based inspection (RBI) is to be conducted for all tanks in addition to inspections at service intervals. Historic tank leakage and failure data are integral to RBI assessments.

Instrumentation

As previously stated, sulfuric acid spills can be extremely dangerous. Therefore, level measurement and control in storage tanks in sulfuric acid service is of the utmost importance. First and foremost, all tanks should be provided with a level indicator. Additionally, high- and low-level switches should be provided on tanks to contain the overspill control and to avoid vacuum conditions when pumps are transferring acid to consuming plants. All instruments are expected to be compliant with safety integrity level (SIL) 2. For more information on SIL classifications, see Tolerable Risk, *Chem. Eng.*, Sept. 2007, pp. 69–74.

For acid storage tanks, the use of radar-type level-measurement devices is recommended, along with control-room alarms. However, many facilities have installed differential-pressure (DP) level-measurement devices without any reported issues. The

FIGURE 3. A metal catwalk on the roof of a storage tank provides some protection for workers, as it is unsafe for personnel to walk directly on a tank's shell

wetted parts of radar level gages should be 316 stainless steel, Alloy 20 or Teflon-lined.

Some older tank farms use a type of tank level-measurement device called a "bubbler system," which uses instrument air as its medium. A small flow of instrument air (forming bubbles) enters the tank near its floor through the level probe. The air introduces some turbulence into the acid near the wall of the tank, which increases the corrosion rate by disturbing the protective $FeSO_4$ layer. Instrument air also contains moisture and oxygen, much of which would likely be absorbed soon after coming into contact with the acid solution [*1*]. Hence, level measurements based on bubbler systems are to be avoided in sulfuric acid storage tanks, especially in spent-acid service, as air can form an explosive mixture with the volatile hydrocarbons present in the acid.

Flow measurement is also an integral part of sulfuric acid handling. Magnetic flowmeters, Coriolis mass flowmeters, rotameters or ultrasonic flowmeters may be used to measure the flow of acid into and out of tanks. As with level instruments, all flow instruments are to be SIL 2 compliant.

Switching of tank service

Some tanks must handle various forms of sulfuric acid, and switching between these materials introduces increased risk. For instance, in some tank farms, tanks must be emptied to switch material-handling service between oleum (an intermediate in sulfuric acid production) and sulfuric acid or between concentrated sulfuric acid and dilute spent acid. These switchovers do not typically require cleaning or draining, simply the removal of as much material as possible via pump. Each switchover represents an opportunity to exacerbate corrosion and potentially release sulfur trioxide (SO_3) vapors or volatile hydrocarbon vapors.

Operators must be attentive and cautious with tanks in oleum service. Oleum is sulfuric acid (100%) containing around 23% free SO_3. In some sulfuric acid plants, oleum is also produced by absorbing SO_3 in concentrated sulfuric acid, and it is common practice to locate the oleum tanks near sulfuric acid tanks. When oleum is introduced in a storage tank, SO_3 fumes are emitted out of the vent, creating visible pollution and a corrosive atmosphere. To curb the SO_3 fumes, small-diameter packed columns filled with random packings (Intallox Saddles are recommended) are fitted on top of storage tanks, as shown in Figure 2. A bleed of sulfuric acid (98%) is taken from the transfer-pump discharge and fed to the top of the packed column to absorb the rising SO_3 fumes from the tank. After absorbing SO_3 fumes, the concentrated sulfuric acid is self-drained into the tank.

Tanks in spent-acid service

Fresh sulfuric acid typically contains 98.4% acid and 1.6% water. Spent acid typically contains 88–95% acid and up to 5% water, with the balance consisting of hydrocarbons, including some light hydrocarbons that can vaporize. A spent-acid storage tank should be designed and operated as if it contained volatile hydrocarbons [*4*].

Special precautions are to be taken in storing spent sulfuric acid in storage tanks. The spent acid comes from various process industries as a byproduct and contains volatile hydrocarbons, which can be released during temperature variations in the atmosphere (thermal breathing). Therefore, blanketing of the storage tanks with an inert gas, such as carbon dioxide or nitrogen is advisable. Also, vent valves are to be provided with emergency tank venting and must be sized for the worst case, taking precautions for scenarios such as a failure of the inerting system (allowing excessive flow of inert gas to enter the tank) or an external fire that volatilizes hydrocarbon liquids in the tank. Additionally, flame arrestors should be placed in the vent line.

Tanks in spent-acid service should be provided with a frangible roof [*1*]. A frangible roof is a weak roof-to-shell attachment that preferentially fails over other welded joints when subject to overpressure. Failure of the roof-to-shell joint pro-

FIGURE 4. Proper care must be taken when executing hot works in the presence of sulfuric acid storage tanks

FIGURE 5. The same tank from Figure 4 was badly damaged after its roof exploded due to hot work on the roof and the formation of hydrogen gas inside the tank while the tank was in service

vides a means to relieve overpressure and to avoid catastrophic failure of the tank and loss of its contents.

Secondary containment systems

Special measures can be taken to ensure that no acid escapes to the environment in the form of secondary containment systems, including the installation of dikes. Dikes are to be built to contain 110% of the largest storage-tank capacity to contain the accidental overspill or catastrophic failure of the tanks. Dikes must also be designed to withstand not only the hydrostatic load of the liquid in the tank, but also for the dynamic tidal-wave effect of liquid-flow load in the case of tank failure. Acid-proof brick lining is to be laid inside the dike so that spilled acid does not permeate into groundwater. In addition to NACE RP 294-94 and API 653, API Standards 650 and 620 also provide helpful guidance in the construction of sulfuric acid storage tanks.

Although dikes can be an extremely helpful measure in protection against tank spills and failures, precaution must be taken when handling the rainwater that collects inside the dike area to prevent environmental contamination. Collected water from dikes in sulfuric acid service is acidic in nature because of the probable leaks of gases from vents inside the dike. This can create environmental issues if released to water bodies without correcting for pH. All rainwater that accumulates inside the dike area should be collected and tested for pH. If required, the pH should be adjusted to ensure it is within the acceptable range, typically 6.5 to 8.5.

Suitable valves must be placed at the dike wall so as to divert the clean rainwater to the dedicated rainwater drain and contaminated rainwater to an effluent treatment plant (ETP). Any accidentally spilled acid is to be collected in spill tanks and neutralized properly before disposal in the ETP.

PPE and HSE

Although sulfuric acid itself is not flammable, it should not be stored near organic materials, nitrates, carbides, chlorates or metal powders. Contact between high concentrations of sulfuric acid and these materials may cause ignition. Proper personal protective equipment (PPE) and health, safety and environmental (HSE) precautions are critical in any facility that handles sulfuric acid. Some best practices for PPE and HSE in sulfuric acid handling are as follows:

1. Suitable eye-wash stations should be located near the tank farm for the safety of personnel. The eye washers are to be tested for their functionality every shift.
2. All of the flanges in the lines are to be covered with lead cladding to protect the operating personnel from accidental acid leaks.
3. Metal catwalks should be provided for working on top of tanks. Operating personnel should always use the catwalk and never walk directly on the tank shell (Figure 3).
4. All lines should be sloped toward the

TABLE 1. GUIDELINES FOR VALVES IN SULFURIC ACID SERVICE
All of the valves in acid tank farms are to be constructed of Alloy 20
Ball valves or plug valves are to be used for isolation purposes
Copper, brass and bronze valves are not acceptable for sulfuric acid service at any concentration

TABLE 2. CRITERIA FOR MATERIALS OF CONSTRUCTION FOR PIPING IN SULFURIC ACID SERVICE

Fluid velocity (m/s)	Material of construction	Temperature limits, °C
0–1	Carbon steel	Ambient
0–2.5	SS 316	Ambient
0–7	Alloy 20	60
For all ranges	Teflon-lined pipe	200

storage tank, or toward the point of consumption. This will prevent the accumulation of acid in low points in the line, thereby eliminating possible safety hazards.

5. Operating personnel should wear gloves that are loose enough to be easily removed in case acid enters them.
6. Helmets should be worn at all times. To ensure eye and face protection, a full face shield and safety goggles are also necessary. Goggles and a face shield are especially crucial when working in a place where splashes can occur unexpectedly. It is essential that eye protection is provided from all angles.
7. In the event of a small spill, one should contain and neutralize the acid with lime.
8. Whenever a modification is carried out in the storage tank area, a hazard and operability (HAZOP) study should be conducted before proceeding to implementation.

Venting requirements

Another crucial aspect to ensuring storage-tank safety is adequate venting. Some best practices associated with tank venting are as follows:

1. Each sulfuric acid storage tank should be provided with an individual breather valve. The vent diameter is to be calculated based on in-breathing, out-breathing and thermal-breathing requirements according to API Standard 2000 [5].
2. The vent area should be greater than the sum of the inlet-, outlet- and drain-line areas.
3. The vent (breather) valve should be kept at the top of the tank. At no instance should it be located at ground level, as it has the potential for inundation in the case of tank rupture or the dike filling with acid or stormwater.
4. If acid switchover (between either oleum and sulfuric acid or concentrated sulfuric acid and dilute spent acid) is routine practice in the tank farm, the vent valves must be sized for the worst-case scenario of vapor release.
5. After decommissioning, the tank should be re-commissioned by introducing acid very slowly, so as to avoid static electricity.
6. The structural integrity of storage-tank roofs is to be inspected in detail.
7. An explosion-proof hatch cover (minimum of 600 mm in size) should be provided on the tank roof.

Transfer pumps

Transfer pumps are used to transfer sulfuric acid from the tank farm to the end-product processing plant or consuming plants (for example, a fertilizer plant), where acid is fed into chemical reactors. Careful attention must be paid to these pumps. Some recommendations for sound transfer-pump operations are as follows:

1. The transfer pumps to the consuming plants shall have a low-level tank trip.
2. The discharge line should be provided with a pressure gage and non-return valve.
3. For the transfer of sulfuric acid from ships at a higher rate, the discharge line should have an excess-flow check valve to prevent accidental spillage of acid to the surrounding environment or to bodies of water.

Hot works in tank farms

Hot works — those tasks that require the use of flames or very high temperatures, such as welding and steel-cutting — must be completed with safety in mind. This is especially crucial in tank farms. The following are some guidelines for executing hot-works tasks in facilities where sulfuric acid is being stored:

1. Hot work is to be permitted only after measuring for flammable gases in the storage tank area. The measurement of flammable gases in the storage tank area is to be done continually during the hot work period.
2. According to API RP 2009, in situations where the work is delayed or suspended in an area that has previously been pronounced gas-free, the permit system should specify the length of time beyond which oxygen and flammability detector tests must be repeated or the

permit reissued [*6*].

3. Periodic combustible-gas and oxygen retests (or continuous monitoring) may be required while hot work is proceeding. The permit should specify the monitoring frequency.
4. If the hot work is to be performed on the shell or roof of the storage tank, and if there are holes in the roof or shell, the tank contents must be emptied and purged with inert gas prior to the hot work.

In many instances, non-compliance with the above measures is a main cause for explosions in sulfuric acid tanks. Figures 4 and 5 illustrate the devastation caused by not taking the proper precautions with hot-works tasks. Figure 4 shows a storage tank in sulfuric acid service. Figure 5 shows the same tank after a catastrophic explosion due to the formation of H_2 gas during hot work.

Pipelines, hoses and valves

Many special design and operating considerations should be taken for piping, hoses and valves that are to handle sulfuric acid. Table 1 provides some best practices for valves in sulfuric acid service. For acid-transfer lines, the pipeline should be of one piping class higher than required to mitigate the risk of accidental rupture or overpressurization.

The materials of construction for piping are dependent on fluid-flow velocities and quality concerns. If iron contamination is a concern for the process, as in the manufacture of caprolactam, carbon steel is to be avoided. Polyvinyl chloride (PVC) and chlorinated PVC are only to be used for vent lines and overflow lines. These pipes should not be used for liquid service. Table 2 provides some criteria for piping materials of construction based on velocity and temperature requirements.

In general, piping should be inspected visually every year. Ultrasonic thickness tests should occur biennially. Depending on the actual plant experience, an increase or decrease in the schedule of inspection may be required. Extra attention should be paid to elbows, tees, valves and any other areas in the piping where flow disturbances (and erosion or corrosion) could occur. Piping inspection criteria from API 570 may be used for guidance [*7*].

A hose lined with polytetrafluoroethylene (PTFE) is acceptable for 93–98% sulfuric acid service. The hose should be designed with a minimum working pressure of 14 kg/cm^2 and be full-vacuum rated. The end fittings must be crimped or swaged. Banding is not recommended. The hose-end fittings should be 316 stainless steel with flanges or quick-connect fittings. The gaskets should be constructed of virgin Viton B materials. The user should have a hose-management program in place to ensure the integrity of hoses. All hoses must be dedicated to sulfuric acid service. [*9*]

Following the guidelines presented in this article will help enable engineers to safely approach the storage and handling of sulfuric acid. ■

Edited by Mary Page Bailey

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An Overview of Filtration

Understanding how different filtration methods work leads to a more informed decision when selecting a filtration system

Alan Gabelman
Gabelman Process Solutions

IN BRIEF

Filtration is arguably the most commonly used unit operation in the chemical process industries (CPI). The range of applications for this important unit operation is very broad — everything from beverage clarification to solids removal from mining ores. If you are associated with the CPI, it is highly likely that you are involved with filtration in some form. This article provides an overview of filtration technology, with an emphasis on solid-liquid separation.

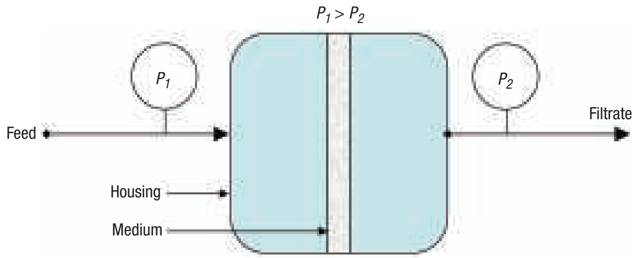


FIGURE 1. The driving force for filtration is a pressure differential

Definitions

Filtration is the physical separation of a solid from a liquid or gas. Although an explicit discussion of gas filtration is outside the scope of this article, the basic concepts discussed here are applicable to gases as well as liquids.

The principle of filtration is depicted in Figure 1, which shows a filtration medium situated inside of a housing. Feed is delivered to the housing upstream of the medium, and a pressure difference across the medium is applied. By virtue of this differential pressure driving force, liquid (or gas) passes through the medium and solids are retained. In practice, this simple model is applied in a number of ways, leading to the numerous types of filters available today. We will delve into a few of these different types (but by no means all) in some detail.

The differential pressure driving force may be applied in one of four ways: gravity, upstream positive pressure, downstream negative pressure (that is, vacuum), or centrifugal force. Simple gravity is the most straightforward method, and it avoids the expense and complexity of auxiliary equipment, such as pumps or centrifuges. However, the amount of differential pressure obtainable by gravity is insufficient for many applications. Upstream positive pressure is probably the most common method, but vacuum filtration is also widely used. Devices that use centrifugal force, a class of centrifuges known as centrifugal filters, are outside the scope of this article (for more on this topic, see Filtration Centrifuges: An Overview, *Chem. Eng.* December 2010, pp. 34–38).

Process design issues

A number of issues must be considered in the design of a new filtration process, or the optimization of an existing one. These include the following:

Feed solids content. This is an important factor in the choice of the type of filter for a given application, as well as the operating conditions. Confusion must be avoided by clearly stating whether the solids content is expressed on a weight or volume basis. Insoluble solids content is usually given in volume percent, but not always.

Particle-size distribution. We often characterize the solids in a slurry by the average particle size. While this is quite useful, the distribution is important as well as the average. The filter must be designed to retain the smallest particles that need to be removed. The tendency for particles to agglomerate, shifting the distribution toward larger sizes, may also be a factor.

Nature of solids. The physical characteristics of the solids have a substantial effect on the level of difficulty of the filtration process, and in turn on the appropriate type of filter and operating conditions. For example, particles that are incompressible (rigid) are usually easier to filter than those that are soft and compressible. If the particles are slimy or gelatinous, filtration becomes even more challenging.

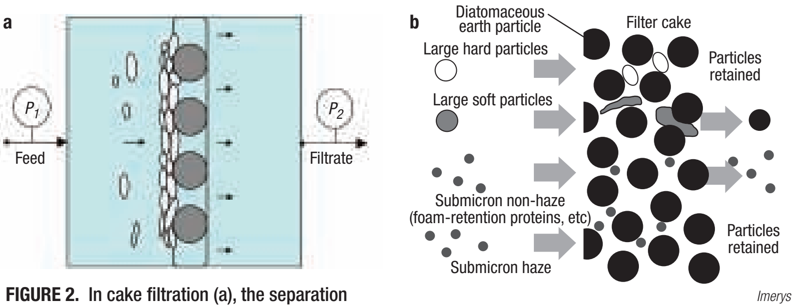


FIGURE 2. In cake filtration (a), the separation takes place on a buildup of particles (cake) on the filter medium. In some cases (b), more than simple size exclusion may be involved

Liquid viscosity. If all else is equal, pressure drop is higher with a more viscous liquid, meaning the flowrate is lower at a given applied differential pressure. Put another way, a higher liquid viscosity results in a lower filtration rate. To reduce viscosity, liquid filtration processes are often operated at elevated temperatures.

Output stream of interest. In many cases the liquid filtrate is the valuable product, and the solids that are removed are waste. However, the opposite may be true, that is, the solids are valuable and the liquid is waste. A third possibility is that both the solids and liquid are valuable, usually with one of the two the main product and the other a byproduct.

Temperature constraints. As mentioned above, filtration processes are often operated at elevated temperatures, to reduce the liquid viscosity, and in turn increase the filtration rate. However, there are constraints. The process temperature must not exceed the maximum allowable operating temperature of the equipment being used. Personnel safety must be considered, with appropriate operating procedures and personal protective equipment (PPE) to minimize the risk of injury. Some products are heat sensitive, and product degradation will limit the maximum acceptable temperature. Finally, rather than filtering hot, temperatures below ambient must be used in some cases. For example, the solids may be soluble, and reduced temperature may be needed to avoid dissolving them.

Productivity and filtration area. The main design specification of a filter is the filtration area. The required area is calculated by dividing the filtration rate per unit area, a number obtained from laboratory or pilot plant experiments, into the desired productivity. For example, if the filtrate rate obtained in the pilot plant is 25 gallons per square foot per hour, and the process specification is 12,500 gal/h, the required filtration area is 12,500/25 or 500 ft^2.

Filtrate clarity specification. How clear does the filtrate need to be? Sparkling clear filtrate may be required, as in some fruit juices or other beverages. In other cases, some turbidity or even some small particulate matter is acceptable or even desirable. Even if high clarity is required, it may be more cost effective to design for a turbid filtrate, then use a finer filter downstream to remove the turbidity. If the solids are the product and the filtrate is waste, clarity is usually unimportant; in the process of removing as much liquid from the solids as possible, some particulates are likely to find their way into the filtrate.

Waste disposal issues. Provisions must be made for proper disposal of waste solids or liquid, consistent with regulations.

Cost constraints. Both capital- and operating-cost targets must be met.

Types of filtration

Filtration processes can be divided into three broad categories. In *cake filtration,* the incoming slurry contains a relatively large amount of solids, enough to form a cake on the filter medium. On the other hand, *clarifying filtration* involves feeds with low solids levels — too low to form a cake. Instead, the solids become embedded in the filtration medium. Finally, with *crossflow filtration* the feed flows parallel to the filtration surface, rather than the conventional perpendicular flow. Crossflow filtration processes employ a semipermeable membrane as the filtration medium, and the name crossflow membrane filtration is frequently used. Membrane filtration is outside of the scope of this article.

Cake filtration

Cake filtration is the most commonly used type of filtration in the CPI. The concept is depicted in Figure 2a, where the dark circles represent the solid portion (for example, fibers) of the filtration medium, and the gaps between the circles denote the flow path for filtrate. Feed is introduced upstream, and a layer of solids is deposited onto the surface of the medium. Some of the particles in this layer bridge the gaps between the fibers, a process that is aptly named bridging. Subsequently, new particles are deposited onto this existing layer, forming a second layer of solids. The process continues, with new solids forming additional layers adjacent to solids already deposited, and in this manner, a cake forms. Rather than the actual medium, the cake itself acts as the filtration medium, determining the quality and flowrate of the filtrate. The role of the actual medium is only to support the cake. Cake filtration is suitable only for feeds containing enough solids to form a cake, nominally at least 1 vol.%. Higher levels of feed solids lead to better results, including improved bridging and more porous cakes.

There are a variety of media available, including paper, textiles, polymers, and even wire screens. Among the materials used are olefins, nylon, polyester, acrylics and fluorocarbons. Both woven and nonwoven media are employed, over a wide range of porosity. When selecting a medium, consider mechanical strength, chemical compatibility with the process material, temperature tolerance, ease of cleaning, and of course, porosity. If the medium is too coarse, solids may become lodged in the openings, leading to blinding. In other cases, solids may not

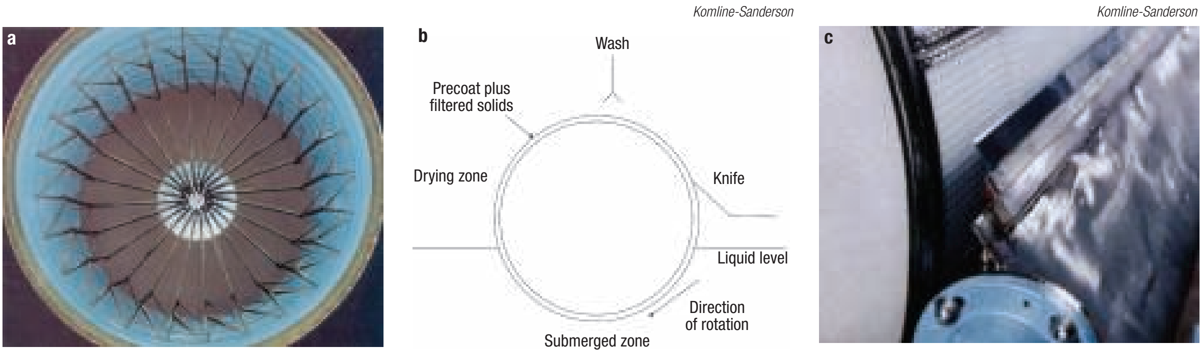


FIGURE 3. The inside of rotary vacuum precoat filter has internal piping (a). During the operating cycle (b), advancing knife cut away filtered solids (c)

be retained and bridging may not occur. Conversely, a medium that is too tight will impose an unnecessary restriction to liquid flow, leading to reduced productivity.

Solids that are soft, slimy or gelatinous tend to pack tightly, forming cakes of low permeability. This problem can be alleviated by the addition of a small amount of filter aid to the feed slurry. Filter aids are inert, highly porous materials that act to separate blinding solids, leading to a more open cake and in turn a higher filtration rate. Filter aid added directly to the slurry is known as body feed. Alternatively, prior to introducing the feed slurry, a layer of filter aid is deposited onto the filtration medium to form what is known as a precoat. These topics are covered in more detail later in this article.

A filter precoated with diatomaceous earth (DE), a common type of filter aid, is represented in Figure 2b. This diagram shows how filtration by simple size exclusion may be an oversimplification. At the top of the figure, rigid particles larger than the openings in the DE precoat are retained, while smaller ones pass through, consistent with our expectation. However, the compressible nature of the large, soft particles shown in Figure 2b allows them to squeeze through, even though the particles are smaller than the openings. The sub-micron, non-haze particles shown in the figure also are not retained, but this is expected because these particles are smaller than the pores in the cake. On the other hand, the sub-micron haze particles seen at the bottom of the diagram are retained even though they are larger than the openings. This is attributable to some mechanism other than physical exclusion, perhaps electrostatic or hydrophobic interaction.

Rotary vacuum filters

These filters comprise a horizontal cylindrical drum that is partially submerged in the slurry to be filtered. The drum is situated in an open tank, known as the tub, which holds the slurry. The inside of the drum contains a network of pipes, connected to openings on the surface of the drum, as depicted in Figure 3a. The surface of the drum is covered with a hard plastic grid, which in turn is covered with the filtration medium, usually a cloth or plastic sheet. In operation, the drum slowly rotates through the slurry in the tub, while vacuum is applied to the internal pipes. Liquid drawn through the medium is carried to a gas-liquid separator (also called a filtrate receiver), while solids are trapped on the surface of the drum. The bottom and top of the separator are connected to the filtrate pump and vacuum source (usually a vacuum pump), respectively.

One type of rotary vacuum filter that is particularly useful is the rotary vacuum precoat filter (RVPF). Here a filter aid precoat is deposited onto the medium before introducing the feed slurry, as in the example in Figure 2b. The operation is shown schematically in Figure 3b. As the drum rotates through the slurry, vacuum draws the liquid into the internal piping, while solids are retained on the surface of the precoat. Upon emerging from the submerged zone, the drum rotates through the drying zone, where as much filtrate as possible is removed.

Some filtrate remains in the cake because of capillary forces, which cannot be overcome by the vacuum. This filtrate is recovered using a displacement wash, which as the name implies, displaces the filtrate retained by the cake with wash solvent (usually water). After washing, filtered solids are cut away by a slowly advancing knife (Figure 3c), along with a thin layer of precoat. In this manner the filtration surface is renewed before the drum reenters the slurry to begin the next pass. This periodic renewal of the surface makes the RVPF a good choice (sometimes the only choice) for solids that blind or otherwise are difficult to filter. Typically the liquid is the valuable stream obtained from an RVPF, because the solids are contaminated with filter aid. However, there are methods of recovering valuable solids in some cases. For example, filtered solids may dissolve with an increase in temperature or change in pH, to be recrystallized later if necessary.

A process flow diagram for an RVPF operation is given in Figure 4. The precoat is formed by charging the tub with a slurry of filter aid in water, then rotating the drum through the slurry with vacuum applied. Filtrate (precoat water) is recycled to the tub until clear, then it is rerouted to the drain as the precoat continues to form. Final precoat thickness may range from 2 to 6 in. If the precoat is too thin, it will be cut away too quickly, increasing the precoat frequency and associated downtime. On the other hand, increased thickness means increased resistance to flow. Moreover, a precoat that is too thick may fall into the tub because the vacuum may be unable to support it.

When the precoat is fully formed, the filter aid slurry in the tub is replaced with the process feed. After displacing the water in the filtrate piping and receiver by process liquid, filtrate flow is redirected from the drain to downstream processing, sometimes automatically based on conductivity, refractive index, or other suitable property. Assuming the filtrate is the valuable stream, the point of switchover becomes a tradeoff between product recovery and evaporation cost.

As shown in Figure 4, the tub is normally fitted with a rake, which is a slow-moving agitator that maintains the solids in suspension. Using an automatic control valve situated downstream of the feed pump, feed flowrate is regulated so that the level in the tub remains constant. If foaming in the filtrate receiver is significant, chemical antifoam can be added as necessary. Some installations use a sensor to detect the presence of foam at the top of the receiver, which triggers automatic addition of antifoam.

When the filtration is done at elevated temperature, the humidity of the gas stream leaving the filtrate receiver is usually rather high. To reduce the load on the vacuum pump, a condenser may be placed upstream to remove some of the water. The height of the filtrate receiver above the filtrate pump must be sufficient to provide the head pressure needed to overcome the vacuum, and avoid pulling the liquid into the vacuum pump. The pipe connecting the receiver and the filtrate pump is called the barometric leg.

Variables. Key variables for optimized RVPF operation are the drum rotational speed, drum submergence and knife advance rate. The first two are set so that a given portion of cake remains submerged only long enough to become saturated with liquid, then the cake stays in the drying zone only long enough for the accessible filtrate to be removed. If too little or too much time is spent in the submerged zone, productivity is lost. Similarly, productivity suffers if the drying time is longer than necessary. On the other hand, if the drying time is insufficient, not only will the subsequent cake wash be less efficient, but perhaps more importantly, the cake will be sloppy and the knife will be unable to make a clean cut. The knife advance rate is set as needed to remove the filtered solids plus a thin layer of precoat. A typical precoat life is 3 to 6 h, with filtration rates ranging from 10 to 100 gal/ft^2/h.

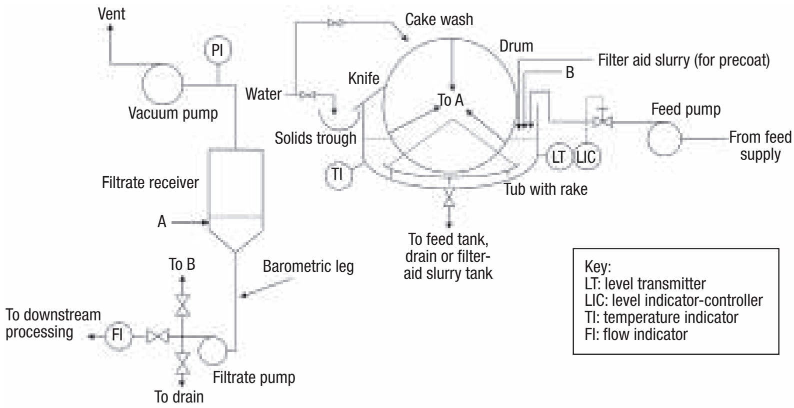


FIGURE 4. Shown here is a typical flowsheet for a rotary vacuum precoat filter

Cake washing. During the cake wash, the displacement of filtrate with water proceeds in a manner that approximates plug flow. Initially the concentration of the displaced liquid is high, but it drops quickly as the water comes through. The required amount of wash is a matter of economics. If the filtrate is the valuable product, use of more wash water improves the yield, but a greater amount of water needs to be removed downstream, usually by evaporation. As with the switchover point following precoating (discussed above), the optimum wash volume becomes a function of the value of the product and the cost of energy. If the solids are the valuable product, then the preferred wash volume is the amount required to reach the purity specification, but no more. In both cases, one to two cake volumes are typical.

The wash assembly is simply a row of spray nozzles connected to a header. Spray nozzles can be obtained in a variety of types and sizes. Data on flowrate and spray angle, both a function of pressure, are available from the manufacturer. The size and type of nozzle, distance between each one, and distance from the header to the cake surface, are all selected to obtain the desired wash volume, with complete coverage of the cake surface and no overlap of sprays. Moreover, the wash header must be sufficiently large so that the pressure drop is insignificant, and the spray through the last nozzle in the line is just as strong as through the first one. In some cases the drum is cleaned between precoats using a separate wash header, designed to deliver a higher flowrate and more powerful spray.

Filter aids

Several types of filter aid are available. Perhaps the one most commonly used is diatomite, which is the skeletal remains of single cell algae, composed primarily of silica. Diatomite, also known as DE, offers the highest clarity of all types of filter aid. Another option is perlite, which is milled volcanic glass composed mainly of potassium aluminum silicate. Because perlite is not as tortuous as diatomite, the high clarity levels achievable with the latter are not possible. Nevertheless, perlite may be more cost effective than diatomite for separation of coarse particles. This is because the density of perlite is lower, so that less material is needed to form a precoat of a given thickness. Other types of filter aid are also used, including expanded cellulose.

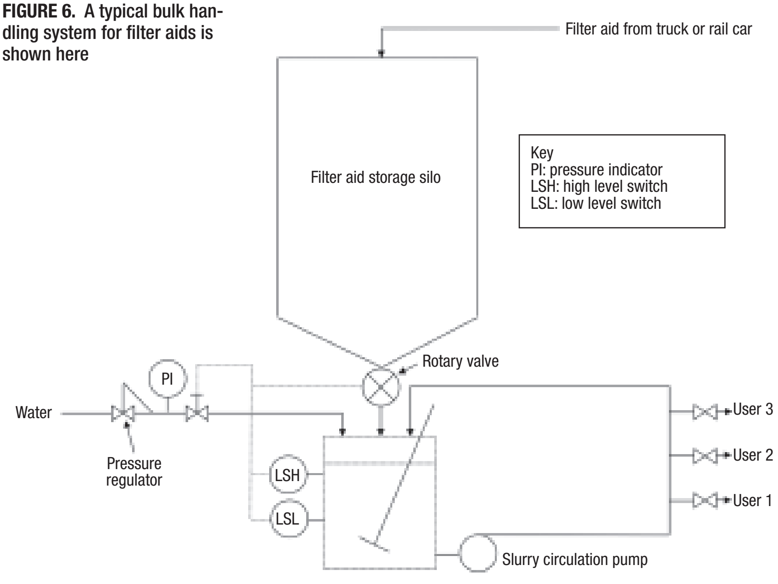
Filter aids come in a range of grades, which differ in porosity, or coarseness. The more coarse grades typically offer higher flowrates, but often at the expense of filtrate clarity. Usually the preferred grade for a given application is the coarsest one that still gives acceptable filtrate quality. In an RVPF application, if the filter aid is too coarse, filtered solids will penetrate into the precoat rather than being retained on the surface. A larger knife cut will be needed to remove them, leading to reduced precoat life and higher filter aid usage.

With large plants, filter aid cost can be significant. Considerable savings can be realized by recovery and reuse of spent filter aid. If waste solids that are removed are heavier than the filter aid, as is often the case with DE, the two can be separated using hydroclone separators. These simple devices, which contain no moving parts, are inexpensive and relatively easy to operate. The aqueous slurry of spent filter aid and impurities (that is, the filtered solids) enters the top of the hydroclone, then moves downward along the wall in a helical pattern. Lighter impurities travel back up the center and exit as overflow. However, the heavier filter aid particles have too much inertia to make the turn, so they exit the bottom as underflow. Of course the separation is not 100% efficient, but enough impurities can be removed to allow reuse of the recovered filter aid.

A three-stage filter-aid-recovery operation with countercurrent washing is shown in Figure 5. Because the optimum separation is usually obtained with a relatively small hydroclone (0.4–48-in. dia. range), each stage actually contains numerous hydroclones in parallel, as needed to reach the required capacity. Feed and wash water are introduced in stages 1 and 3, respectively, so that the cleanest wash solvent contacts the cleanest solids. The overflow from stage 1, enriched in impurities, is directed to waste treatment, while the underflow from stage 3, enriched in filter aid, is reused.

For small plants with relatively low usage, filter aid is supplied in bags. On the other hand, bulk storage and handling are more cost effective for high volumes. A flow sheet for a bulk system is shown in Figure 6. Filter aid delivered by truck or rail car is unloaded into a storage silo, using a pneumatic conveying system. Dry filter aid is added by gravity to a mix tank via a rotary valve, where it combines with water to form a slurry. Flow of water and filter aid into the tank are started and stopped when the tank level reaches low- and high-level switches, respectively. The water pressure is set to obtain the desired flowrate, and the speed of the rotary valve is adjusted accordingly, to achieve the targeted slurry concentration. Continuous circulation through the plant then back to the mix tank is necessary, to avoid settling and subsequent clogging of pipes; the required linear velocity is typically 9–10 ft/s. Users remove slurry from the loop as needed via T connections, with piping that is designed to minimize dead spots that would be prone to clogging, and washout ports to remove clogs that do form. In addition, a bare metal pump is not suitable for the highly abrasive filter aid. To avoid rapid erosion of the impeller and casing, both are typically lined with rubber.

FIGURE 6. A typical bulk handling system for filter aids is shown here



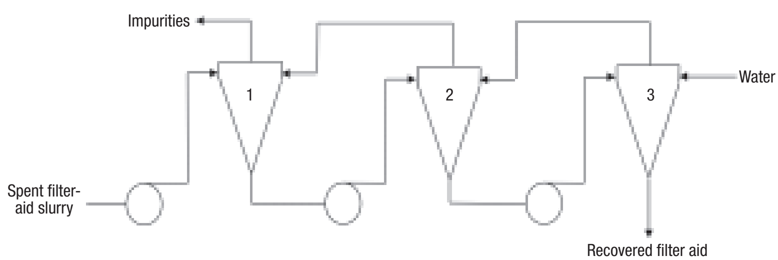


FIGURE 5. Hydrocyclones are used in this three-stage filter-aid recovery process with countercurrent wash

Laboratory dip leaf

This device is used to simulate RVPF operation in the laboratory. The data can be used for feasibility assessment, to size a production filter, or to optimize operating conditions for an existing one. The laboratory dip leaf (Figure 7) comprises two cylindrical, threaded stainless-steel sections, arranged so that the top one screws into the bottom one. The bottom section contains a perforated plate that supports the filter medium, and a bottom outlet for filtrate flow. As shown in Figure 7, the filtrate outlet is joined via flexible tubing to two graduated filtrate receivers connected in parallel, and in turn to a vacuum source. With two receivers, the operator can fill one at a time, switching to the empty one and draining the full one as needed. There is also a feed vessel (typically a few liters in volume), which may be jacketed

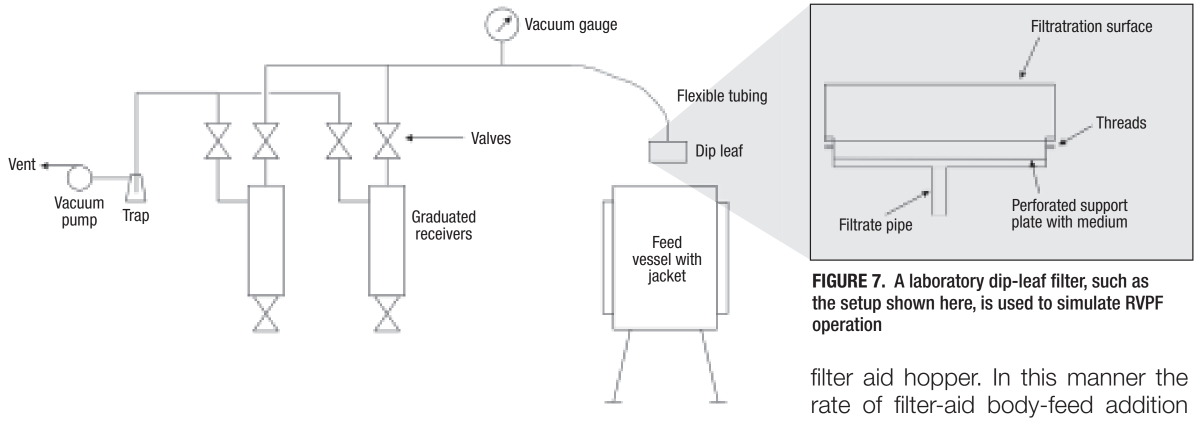


FIGURE 7. A laboratory dip-leaf filter, such as the setup shown here, is used to simulate RVPF operation

for temperature control. The vessel may also be equipped with a mixer, but simple manual mixing using a wooden paddle is usually sufficient.

In operation, filter aid slurry is charged to the feed vessel, vacuum is applied, and then the dip leaf is immersed in the slurry. Water collects in the receiver, while filter aid solids are retained and form the precoat. Once precoating is complete, the precoat is trimmed flush using a scraper blade, receivers are emptied, filter aid slurry in the feed tank is replaced with process slurry, and testing begins. The dip leaf is immersed for a specific period of time, then removed and allowed to dry for a specific amount of time. If desired, the cake can then be washed using a spray bottle. Afterward, the top piece is screwed into the bottom a specific amount (usually with the aid of graduations on the rim), bringing a small amount of cake above the rim. This thin slice of cake is removed using the scraper. The volume of filtrate obtained is noted, then the dip leaf is immersed for a subsequent dip.

The process is repeated until the volume of filtrate obtained per dip is consistent, then a new dip time, drying time or thickness of cake removed per dip can be evaluated. These three parameters are easily converted to percent submergence, drum rotational speed and knife advance rate of an actual RVPF. In this manner, conditions are found that maximize productivity while minimizing filter aid usage. The dip leaf can also be used to study other aspects of RVPF operation, including operating temperature, wash volume, type and grade of filter aid, and filter-aid slurry concentration.

Pressure leaf filter

A pressure leaf filter contains a series of heavy screens or grooved plates, called leaves, situated in a housing. Each leaf is covered with the filter medium, usually a cloth bag or fine metal screen. Slurry is delivered to the housing, then by virtue of the applied pressure, liquid passes through the medium while solids are retained on the surface. The filtrate flows through the internal part of the leaf, then exits through the bottom outlet. The process ends when the filtrate flowrate becomes too low, the pressure in the housing gets too high, or the cake holding space fills. At that time the housing is opened and the cake is discharged by one of several methods. The most common method is to simply wash the cake off with a water spray, a technique known as sluicing. If a dry cake is desired, the liquid is displaced by hot gas (usually air or nitrogen), then the dry cake is removed by vibrating or spinning the leaves.

Unlike the RVPF, the pressure leaf filter cannot handle highly difficult filtrations because the filtration surface is not renewed, although the use of body feed is often helpful. On the other hand, the pressure leaf filter is less expensive, and simpler to operate and maintain.

A process flow diagram for a pressure leaf filter is shown in Figure 8. Slurry flow is controlled to maintain a constant level in the feed tank, and the flowrate determines the speed of the rotary valve at the bottom of the filter aid hopper. In this manner the rate of filter-aid body-feed addition changes with slurry flowrate, keeping the relative amount of body feed constant. Anywhere from 0.2 to 2 lb filter aid per pound of slurry solids may be needed, depending on the nature of the solids. Cake is removed by sluicing with water, although there are options for dry cake discharge as mentioned above. Prior to introducing the process slurry, a precoat may be applied if desired, using the precoat tank and pump. Unlike those used with an RVPF, the precoat is relatively thin, typically about 0.25 in.

Laboratory data for feasibility assessment, optimization or design of a pressure leaf filter (as well as other types of pressure filters) can be obtained using a small (typically a few liters) cylindrical pressure vessel. The vessel is fitted with a perforated plate near the bottom, to support the filter medium, as well as a bottom outlet. If desired, a jacket may be provided for temperature control. In operation, the tank is filled with the process slurry, the vessel is maintained at the desired pressure using compressed gas (usually air or nitrogen), and then the volume of filtrate collected over time is recorded. The data can be used to size the required production filter, employing methods described in textbooks on filtration or chemical engineering unit operations.

Filter press

This is perhaps the oldest filtration technology still in common use. A filter press contains a series of alternating solid plates, with grooves or perforations for filtrate flow, and hollow frames, which provide the cake holding space. Alternatively, recessed plates may be used without frames, with the recess serving as the cake holding space. The plates and frames, or recessed plates, hang vertically on parallel support bars to form a plate pack, which is closed between two end plates. Smaller plate packs can be opened and closed manually, while hydraulics are used for larger ones. Each plate is fitted with the filter medium, usually cloth or stiff paper. Feed slurry is directed to the cake holding spaces; solids are retained by the medium, while filtrate passes through the grooves or perforations on each plate prior to exiting.

Filter presses offer numerous advantages, including simplicity (no moving parts), relatively low cost, and versatility. Capacity can be changed easily, by adding (up to the capacity of the frame) or removing plates. The filter media are readily accessible for cleaning or replacement, simply by opening the plate pack. Floor space and headroom requirements are low, and relatively dry, dense cakes are obtainable.

However, there are also disadvantages. Filter presses are labor intensive; cleaning or replacement of the media is done manually. Moreover, when the plate pack is opened, the operator is exposed to the process material, which precludes applications involving hazardous materials without special measures for personnel protection. Finally, filter presses are prone to leakage, which is a nuisance at best, and more serious if the process material is hazardous. For these reasons, pressure leaf filters are often preferred for new applications, with the exception of pilot or small production operations.

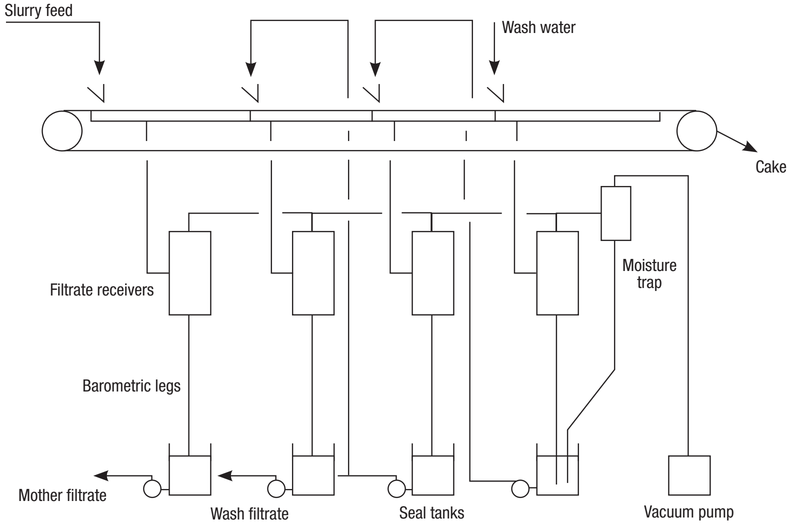


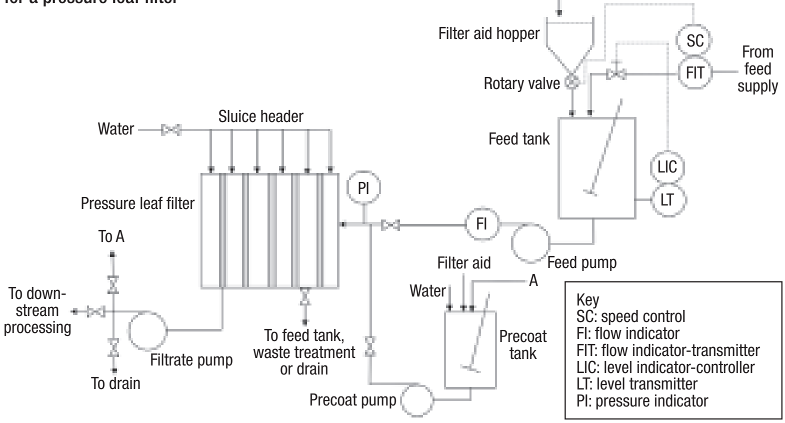
FIGURE 9. A schematic for a horizontal belt filter (Source: www.solidliquid-separation.com)

Horizontal belt filter

This is the most commonly used vacuum filter in the CPI, mainly because of its flexibility, ability to handle corrosive slurries, and high throughput. As shown in Figure 9, the horizontal belt filter contains a belt that moves through cake formation, washing and drying zones in an endless loop. Slurry is introduced at one end, with liquid pulled through the belt by the applied vacuum (typically 24–26 in. Hg), while solids are retained to form the cake. Wash water, introduced just upstream of the drying zone, provides a countercurrent washing effect, with the cleanest wash solvent contacting the cleanest cake. Upon reaching the downstream roller, the cake is discharged by virtue of the change in direction, then the underside of the belt is washed prior to the next pass. The belt, which uses raised edges to contain the liquid, may be as large as 12 ft by 90 ft and travel at speeds up to 3 ft/s. Cake thickness and solids holding capacity are 1/8–6 in. and 2–100 lb solids per square foot, respectively.

Key design variables are the lengths of the feed, washing and drying zones. A longer washing zone may be needed for higher cake purity or greater recovery of filtrate. A low filtration rate would require all sections to be longer. Important operating parameters are feedrate and belt speed, which are optimized to maximize productivity while still obtaining a reasonable cake thickness, adequate liquid removal and suitable solids purity. The cake must be sufficiently thick to easily fall from the belt at the discharge end, yet not so thick that there is insufficient time or too much resistance to flow for the cake to dry adequately. Cake thickness can be reduced by decreasing the feedrate or increasing the belt speed, which may be necessary for high solids feeds.

FIGURE 8. The process flow diagram for a pressure leaf filter



Cartridge filters

Cartridge filters use one or more cylindrical cartridges situated in a housing. Feed is directed to the outer surface, then filtrate flows through the cartridge to the hollow center and out, while particulates are trapped. Unlike the cake filters described above, the solids do not form a cake on the surface of the medium (that is, the cartridge). Feed solids should be low (<1 vol.%), or the cartridge will become dirty and require cleaning or replacement too quickly. A typical cartridge diameter is 2.75 in., with lengths ranging from 10 to 40 in. Porosities vary widely, from submicron sizes up to 100 µm, but as discussed below, micron ratings must be interpreted cautiously.

Fibrous cartridges are discarded once they are fully used, as indicated by a substantial decrease in flowrate or increase in pressure drop. Alternatively, stainless-steel cartridges can be cleaned and reused, and also offer higher temperature compatibility.

Cartridges may be the surface type or the more common depth type. As the names imply, with the former the solids are retained on the surface, while with the latter they are embedded within the medium. A popular depth filter is the yarn-wound variety, where yarn is wound around a central core. Usually this is done in such a way that the openings are largest near the outside, then become progressively smaller toward the center. Consequently the larger particles are trapped near the surface, and the smaller ones are captured closer to the core. The yarn can be any fibrous material, including cotton, glass, polyester, nylon, or polytetrafluoroethylene (PTFE). Cores can be polypropylene, phenolic resin, stainless steel, or other metals or alloys. Bonded cartridges, made from long, loose fibers impregnated with phenolic resin, are self-supporting and do not require a core.

Surface filters use media that are pleated, for increased surface area, usually with multiple, concentric pleated sheets wrapped around a central core. The sheets can be made from any thin material that can be folded without cracking, including cellulose, polyester, fiberglass, PTFE, and polyethersulfone. Some cartridges use a semipermeable membrane, which can be made with pores as small as 0.03 µm. These membrane cartridges are employed in applications that require highly pure filtrates, such as for production of ultrapure water in electronics processing, cold pasteurization of beverages, or sterilization of fermentation media. Examples of membrane cartridges are shown in Figure 10.

Housings are available in a number of shapes and sizes. Most housings accommodate multiple cartridges, although small housings that accept a single 10-in. cartridge are also made. Most cartridges use a gasket or O-rings to seal the open bottom against a mating surface in the housing. The top may be open or closed, designs that are called double open end (DOE) and single open end (SOE), respectively. The DOE cartridge seals against the top cover, while no top seal is needed with the SOE design. A DOE cartridge is depicted on the left of Figure 10, while an SOE design is shown on the right; the top of the latter contains a so-called spearhead, which fits through a perforated plate to locate the cartridge and stabilize its position.

In some applications a cartridge filter serves as a polishing filter, situated downstream of a coarse filter or centrifuge. This is because it may be more cost effective to design the upstream separator to deliver a liquid containing a small amount of particulates, to be removed using cartridges, rather than trying to reach the final clarity specification in a single step. In other applications the cartridge filter serves as a guard. Under normal operation, an upstream separator produces liquid of the required clarity, with little or no improvement upon passing through the cartridge filter. However, if there is an upset that allows solids to escape the upstream separator, they are captured by the cartridge before contaminating the downstream process.

Rosedale Products

FIGURE 10. Two types of filter cartridge are shown here: the double open end (DOE) cartridge (left) is open at both ends; the single open end (SOE) cartridge (right) contains a spearhead in the closed end

Zeta potential filters

Zeta potential is the net charge exhibited at the surface of a particle when placed in aqueous solution. The value, a result of interactions between the particle and the liquid, varies with the ionic character of the particle, as well as the pH and ion content of the liquid. Because many particles, including microorganisms, clays, silica and others, have a negative zeta potential, filtration is enhanced when a filter medium with a positive zeta potential is used. This can be achieved by attaching suitable functional groups to the filtration medium. The resulting filtration process leverages electrostatic interactions as well as physical size exclusion, allowing capture of particles smaller than the openings in the medium.

Cartridge removal ratings

In principle, the removal rating is the maximum particle size the cartridge will allow to pass. For example, a 30-µm cartridge might be expected to retain all particles with sizes of 30 µm and larger, with smaller ones appearing in the filtrate. However, the real situation is not so straightforward.

Ratings can be nominal or absolute. A cartridge with a nominal rating is purported to retain a percentage of particles the same size or larger than the rating. For example, a 30-μm nominal cartridge may have retained 98% of particles 30 μm and larger in a laboratory test. On the other hand, a 30-μm absolute cartridge should retain all particles 30 μm and larger, consistent with the expectation described above.

Nominal ratings are assigned by introducing the test feed upstream, then analyzing the filtrate to determine the percentage of particles of a given size that were removed. This sounds simple enough, but there are numerous drawbacks. There is no standardized test procedure. That is, operating conditions (temperature, pressure, flowrate), solids composition and concentration are at the discretion of the manufacturer. Moreover, removal criteria are not consistent. For example, one supplier may offer a 30-μm cartridge that, when tested, removed 98% of particles 30 μm or larger (the example given above), but another manufacturer's 30-μm cartridge may have removed only 95% of these particles. Because of the lack of standardization, micron ratings of different manufacturers cannot be compared.

There are other drawbacks as well. Test results are not always reproducible. With some cartridges (for instance, felts, woven yarns and loosely packed fiberglass), pores can shift during operating, releasing trapped particles and complicating characterization efforts. Finally, and perhaps most important, the test feed used to determine the cartridge performance is rarely, if ever, the same as the process material, and results are likely to be different.

The situation is better with absolute filters, but there are still issues. There are standardized test procedures that specify operating conditions, test material and particulate concentration. Examples are ASTM STP 975, or the modification developed by the 3M Corp. for ratings of 20–100 μm, and ASTM F 838-83, used for tight filters designed to remove microorganisms. However, not all manufacturers use the same test, and results vary from one to the other. Moreover, performance can change during the life of the cartridge, meaning filtrate emanating from a new cartridge may not be the same as filtrate obtained when the cartridge is nearly spent. And again, the test material is unlikely to be the same as the process material.

Bag filters

Bag filters comprise a bag made from a polymer such as polyester, nylon or polypropylene, supported by a stainless-steel screen inside of a cylindrical housing. The feed enters the inside of the bag, then liquid flows through the bag to the exit port while solids are retained. Bags with nominal ratings of 1–1,500 μm are available.

Bag filters are usually used to treat slurries containing at least a few percent solids. The solids gradually fill the bag, which is then replaced with a fresh one. While this is reminiscent of cake filtration, the retained material is usually too wet and loosely packed to be considered a cake. The main advantages of bag filters are simplicity and low cost. On the other hand, bag filtration is labor intensive, making it unsuitable for large-volume operations, and the operator is exposed to the process material. ■

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Large-Scale Fermentation Systems: Hygienic Design Principles

Follow these tips to optimize systems that use microbial fermentation to produce biochemicals and biopharmaceuticals

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Fermentation has always been an important part of human history. Human beings are known to have made fermented foods since Neolithic times. With the discovery of microorganisms in the 19th century, fermentation became a viable route to produce synthetic chemicals and antibiotics. Between 1900 and 1930, fermentation was the primary route for producing alcohols and acetone. But with the advent of cheaper oil, chemical-synthesis routes became the preferred route for producing alcohols and other solvents.

Due to the recent emphasis on the use of renewable resources, interest in microbial fermentations has been experiencing a renaissance. The intent is to use abundant and renewable raw materials, such as non-food crops, agricultural wastes and algae, to produce a broad array of desired chemicals or biofuels. While some biorefineries that use these feedstock materials will use naturally occurring microorganisms to produce the desired chemical products, most of them will rely on new organisms that have been genetically engineered to favor the production of the target products.

Challenges

The challenges associated with designing large-scale biochemical production facilities are very similar to those related to the design of facilities producing biopharmaceuticals. The genetically modified microorganisms (GMM) used in both types of facilities are, often by design, not very robust; thus, they often find it difficult to compete against microorganisms occurring in nature (in general, highly specialized breeding in a microorganism tends to reduce its viability overall). This is also a safety consideration. Since you are creating a novel microorganism, just in case it exhibits some unforeseen undesirable traits, you don't want it to be able to outcompete natural organisms.

Therefore, preventing contamination of the bioreactor/fermentor systems is of paramount importance in both biochemical and biopharmaceutical facilities. In biopharmaceutical plants, this is accomplished by incorporating extensive clean-in-place (CIP) and sterilize-in-place (SIP) systems, and using components and equipment that lend themselves to being cleaned and sterilized in place. These requirements result in very expensive construction, as most components are made of highly polished stainless steel, and all vessels are designed for 25 psig or higher pressure and full vacuum to withstand steam-sterilization conditions.

The same principles can be applied to the design of large-scale biochemical production, but this needs to be tempered by the fact that different economic drivers are in play. While biopharmaceutical production facilities yield products that sell for thousands of dollars per gram, biorefineries often produce products that sell for, at most, a few dollars per kilogram. The other big difference between biopharmaceutical facilities and industrial biorefineries is that the latter apply industrial-scale fermentation to produce bio-based chemicals and plastics on a scale that is orders-of-magnitude larger than the scale typically used for biopharmaceuticals production.

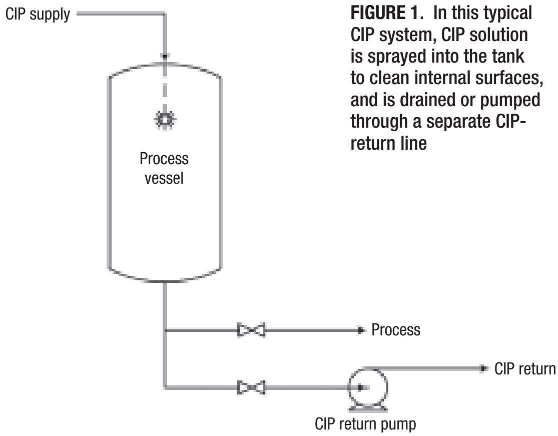

FIGURE 1. In this typical CIP system, CIP solution is sprayed into the tank to clean internal surfaces, and is drained or pumped through a separate CIP-return line

As a result, the ability to meet the potential demand for chemicals that are produced by fermentation will likely require the development of fermentors with a capacity in the range of hundreds of thousands of gallons or larger. Many of the easy-to-clean and easy-to-sterilize components that have been developed for food and pharmaceutical production do not exist at the scales that are seen in the production of industrial biochemicals.

There are no precise definitions or cutoffs with regard to scale. Today, the largest cell-culture bioreactors to produce biopharmaceutical products have a capacity of about 25,000 L (6,500 gal). This article discusses many of the problems that can arise related to large-scale industrial fermentation vessels (that is, those with a capacity up to 1 million gal) that are increasingly being used for industrial bioprocesses. It also presents recommendations for appropriate CIP and sterilization design for large-scale systems.

CIP design considerations

In addition to preventing contamination by foreign living organisms, CIP systems are also used to remove non-biological contaminants, such as grit, scale and organic matter, which may also have an adverse effect on process performance.

CIP sequence. CIP systems achieve these objectives by removing dirt by impact or turbulence, and by breaking up and removing remaining dirt by chemical action. Figure 1 shows a typical arrangement for cleaning a process vessel.

The CIP system supplies CIP fluid to a spray device inside the vessel, which sprays the solution onto the vessel walls. A variety of spray devices are available, including static sprayballs (Figure 2) and fluid-driven orbital cleaners (Figure 3). Sprayballs are high-flow, low-pressure devices that are often used to clean smaller tanks (typically smaller than 15-ft-dia.). Fluid-driven orbital cleaners are low-flow, high-pressure devices that are typically used to clean larger tanks (greater than 15-ft dia.). Line cleaning is accomplished by circulating CIP fluid in the pipeline.

A typical CIP sequence includes the following elements:

Process heel drain. A complete drain of the heel is needed to minimize waste and avoid contamination of the CIP fluid.

Initial or pre-rinse. The primary objective of the initial rinse is the mechanical removal of dirt. Water recovered from a later step in the CIP sequence is used for the pre-rinse step. Note that the pre-rinse effluent stream may contain genetically modified microorganisms, and thus will need to go through a bioinactivation process before being sent for further waste treatment.

Detergent wash. This step involves chemical cleaning to remove remaining dirt. The detergent solution is circulated through the system. The solution type and concentration should be determined by plant experience. While a 2–4% caustic solution is commonly used in this step, an acid-based detergent (or both) can also be used, depending on the type of dirt or other contaminants present.

FIGURE 2. Typical static sprayballs, which use high flow and low pressure to clean the internal surfaces of a tank, are shown here

Spraying Systems Co.

Water rinse. A once-through rinse of clean water is typically used, with no circulation, and this substantially reduces the amount of residual materials from the detergent wash step. If no acid wash is used in the CIP sequence, this water rinse step becomes the final rinse prior to either sanitization or sterilization. The rinse water should be collected for reuse as the pre-rinse fluid used in the next CIP cycle.

Acid wash. The solution used in this step may be circulated in a loop (similar to the detergent wash), and this step serves two functions. The first is to quickly neutralize and remove any remaining caustic from the detergent wash step. The second is to remove any hard-water-scale deposits that may occur within the process equipment. As mentioned earlier, depending on the nature of the dirt, an acid wash may be required to ensure dirt removal, as well.

Water rinse. This additional water rinse step is only required if an acid wash is used (to remove the bulk of any acid wash solution that remains after the acid wash step). The water from this step is collected and reused as the pre-rinse in the next CIP cycle.

CIP system configuration. There are several different CIP system configurations that can accommodate the CIP sequence described above. They vary from a single-tank system, which is based on single use of detergent solutions and rinse water, to multi-tank systems, which allow for the recovery of these fluids. Figure 4 shows a typical configuration for a multi-tank system. If an acid wash is not required, the number of tanks can be reduced to three.

Heat-recovery and caustic-recovery modules are optional and are rarely included. Depending on the location, type and elevation of the process equipment, the facility could operate several CIP systems that are dedicated to different process areas, rather than a single system.

Even if one central CIP system is possible, it may include two supply and return headers. If there is more than one GMM used in the facility, or a combination of GMM and non-GMM, then providing separate CIP systems for the different microorganisms is advisable to prevent cross-contamination.

Equipment sizing. Process systems that are subject to CIP are divided into CIP circuits. For example, a process vessel may constitute a circuit. Piping coming out of the vessel may constitute another circuit. At times, the vessel and associated piping may be combined into one circuit. Equipment in the CIP system should be sized for the highest-possible anticipated flow and volumetric capacity requirements of the given CIP circuit. If the CIP system is designed to clean more than one circuit at a

Gamajet

FIGURE 3. This photo shows three kinds of orbital, in-tank cleaners that are widely used in large-scale fermentation vessels

time, then the system should take into account the requirements of all the circuits that may be cleaned simultaneously. Generally, CIP systems are designed to clean one or two circuits at a time.

Tank design. Tanks are typically constructed from 304L or 316L stainless steel. Internal welds should be ground smooth and dead spots should be minimized. Internal polishing of CIP vessels is usually not required. Detergent tanks should be equipped with agitators to ease the preparation of detergent solutions.

It is important to include provisions for periodic cleaning of the CIP system. This requires that the CIP tanks be equipped with sprayballs or orbital cleaners. CIP tank volumes are determined as follows:

Pre-rinse tank. The volume of this tank is calculated as a function of the highest CIP flow volume, multiplied by the duration of the pre-rinse step. Typical pre-rinse times are 15–20 min for vessels, and 5 min for pipes.

The pre-rinse tank usually stores the water from the final rinse. If the pre-rinse and final rinse volumetric requirements are the same — which is often the case — then the pre-rinse tank is sized to hold the final rinse volume.

If the pre-rinse uses fresh water, then the size of the tank is equal to the maximum CIP flow, multiplied by the duration of the pre-rinse, minus fresh water makeup capacity.

Detergent tanks. These tanks need to have sufficient volume to fill the CIP circuit with detergent solution, to enable recirculation, and to allow for losses, which will occur during switchover from water rinse to detergent wash and vice versa.

Final rinse tank. The volume of this tank is equal to the highest CIP flowrate multiplied by the duration of rinse, minus fresh water makeup. This tank can be very small if the makeup rate is equal to the rinse flow requirements.

Pump design. The CIP supply pump design is an additional, complex issue. There will likely be a variety of unit operations and tanks using the same CIP solutions, but with differing flow and pressure requirements. To address this engineering challenge, variable-speed drives or parallel pumps (systems with different flows and heads) may be used to meet the range of requirements.

Hydraulic losses for spray nozzles and equipment (heat exchangers, sterilizers and more) need to be calculated based on vendor information. CIP flows may be higher than the design process flows. Therefore, values for design pressure drop may not be accurate. Sprayballs usually require 20–25 psig pressure, and spray nozzles and orbital cleaners can require up to 250 psig.

The pumps are normally centrifugal pumps, often with variable-speed drives. NPSH requirements are an important consideration, due to the elevated temperatures required for some CIP fluids.

Low available NPSH is especially a problem in CIP return service during tank cleaning. This is because the cleaning fluid is often close to the boiling temperature and there is no static head because there is no liquid level in the tank during cleaning. One option (perhaps the best option) is to use sanitary liquid-ring, self-priming pumps, such as the one shown in Figure 5. Self-priming pumps have the ability to pump fluids with entrained gases.

However, some systems have flow and capacity requirements that exceed capabilities of currently available sanitary self-priming pumps. In those cases, consideration should be given to non-sanitary self-priming pumps.

Materials of construction. The materials of construction for all process equipment and piping will need to be compatible with both the process fluids and the cleaning agents. In general, type 304/304L stainless steel will be satisfactory for wetted surfaces. However, depending upon the piping specification, type 316/316L stainless-steel material may be a less costly option, especially if stainless-steel tubing is used in smaller diameters. Elastomers and gasket material must be checked for compatibility with the cleaning agents, particularly considering the elevated temperature of the caustic wash solution. Aluminum, copper and bronze materials should not be used in the process areas, and are not acceptable in wetted portions of the CIP system.

Piping design. Key considerations of piping design for the CIP systems and the process systems being cleaned include the proper design of CIP circuits, the ability to drain CIP lines, and the appropriate segregation of the CIP system from the process being cleaned. Ideally, any dead legs should be no longer than two pipe diameters, and the overall system should be designed to drain completely. Significant biological growth can occur in water that has been allowed to stand stagnant even for short periods of time.

Lines should be sized for fully turbulent flow. The general practice is to have a velocity range of 5–7 ft/s. Individual CIP circuits must be designed so that every line in a circuit maintains the appropriate velocity.

Reducers in horizontal lines should be eccentric and installed with the flat side on the bottom of the pipe. All horizontal lines should be sloped to a drain point, and low points must be equipped with drains. The minimum slope of the pipe should be at least 1/16 in. per ft.

Valve selection should be done with care to avoid non-drainable conditions or crevices that will not be cleaned. So-called "clean" ball valve designs are available for sizes 6 in. and less. For larger sizes, hygienic butterfly-valve designs should be considered.

The tie-in point between the CIP system and the process is critical. Ideally, connections to the process

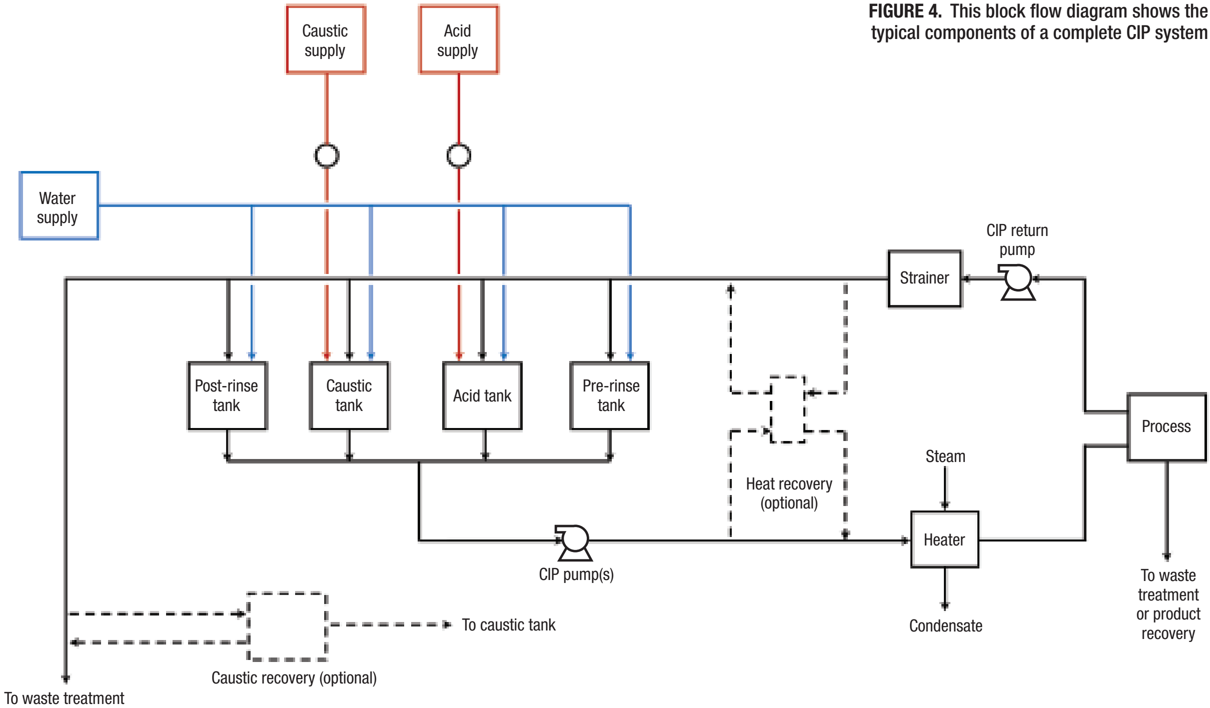

FIGURE 4. This block flow diagram shows the typical components of a complete CIP system

should be either a block-and-bleed connection, or a line break. Specially designed, mix-proof valves are available for this service, but are limited to 6 in. or smaller in size. In some cases, flow-transfer panels may be used to restrict the connection of cleaning circuits and to provide a positive break between the process and the CIP system. The severity of potential consequences that could arise from leakage of the CIP solution into the process should guide the system designer when establishing an appropriate level of separation between CIP and process systems.

CIP flowrate. Determining the design flowrate for the CIP system requires knowledge of the number and types of systems and accessories to be cleaned. Turbulent flow conditions are required for effective pipeline CIP. This is achieved when the fluid velocity is between 5 and 7 ft/s. Table 1 shows flowrates that correspond to fluid velocity between 5 and 7 ft/s for various pipe sizes.

A flowrate that produces this velocity range will be adequate for cleaning in-line equipment, as well. There are possible exceptions that should be checked. For instance, some heat exchangers and filter housings may have a larger cross-sectional flow area than the pipe feeding it. Flowrates and pressure drops should be calculated separately for this equipment.

Flowrates required for equipment cleaning depend on the process, organism and type of dirt to be cleaned. Typical minimum flow values for vertical tanks and reactors range from 2 to 3 gal/min per foot of tank circumference. Additional flow and spraying devices may be required, depending on the number and locations of large nozzles, dip tubes, baffles and other internal obstructions.

The choice between sprayballs and orbital cleaners is driven by vessel size and type of dirt. As vessels get larger, flow requirements for sprayballs become very large (often excessively so); thus orbital cleaners become a more economical choice. Another reason to choose a high-pressure orbital cleaner is when a high-impact force is required for effective CIP. Close coordination with spraying device vendors is required for proper device selection.

Instrumentation and controls. The extent of instrumentation in the CIP process depends on the automation philosophy in the plant. In general, recommended instrumentation includes the following:

- Visual sightglasses for CIP supply and return lines
- Temperature indicators on the caustic, acid and rinse water tanks
- Conductivity transmitters in the CIP supply and return lines
- Temperature indication and control on the CIP solution heater
- Temperature indication in the CIP return line
- Level indicators on all tanks
- Differential pressure indicators across filters and heat exchangers
- Limit switches confirming position of crucial valves

Automation. Full automation of the CIP process is recommended. The only exception to full automation would be in rare cases where flow-transfer panels are used to isolate the CIP system from the process. A variety of items in the CIP system should be automated, when possible. These include sequencing of valves for circuit lineup, minimum circulation times, permissive inputs between steps, cycle stops and alarms for CIP process values. Automation should allow for stopping, repeating or increasing the duration of steps in the CIP process.

FIGURE 5. The liquid-ring centrifugal pump shown here is able to pump fluids with low suction head and entrained air

TABLE 1. FLOWRATES FOR TYPICAL PIPE SIZES		
Nominal pipe size	Flow, in gal/min, for Schedule 10 pipe	
	5 ft/s	7 ft/s
1	15	21
1 ½	35	48
2	57	80
3	130	182
4	222	311
6	495	692
8	849	1,189
10	1,329	1,860
12	1,879	2,630

Sterilization

In a typical biopharmaceutical process, CIP is followed by equipment sterilization. While the goal of CIP is to clean equipment surfaces (including the removal of any microorganisms found on the surfaces), the goal of sterilization is to destroy residual microorganisms (even down to trace amounts), that are still present after the CIP cycle is complete. This is particularly important in processes involving long-running mammalian cell cultures, where the presence of even one contaminating microorganism can be disastrous.

The most common technique for sterilization of large-scale process equipment is moist-heat sterilization with steam. The steam-sterilization process typically involves the following three steps:

- Displacement of air with steam and heating to sterilization temperature, usually 250°F
- Holding at sterilization temperature for a minimum of 15 min (although 30 min to an hour is more common)

- Cool down, which includes introduction of sterile air to prevent a vacuum condition resulting from steam collapse as the equipment cools off

Since the pressure of 250°F saturated steam is 15 psig, this means that the equipment undergoing steam sterilization needs to be rated for a pressure higher than that. And since the usual practice is to use steam at pressure greater than 20 psig to ensure a margin of safety, this typically translates into a 25–30 psig design pressure for equipment undergoing conventional steam sterilization.

This would be prohibitively expensive for the relatively low-value products that are typically produced in large-scale biofuel or biorefinery plants. As mentioned, fermentors and other vessels in such plants can range in size from 100,000 to 1,000,000 gal. This calls for a different approach to sterilization — one that would allow these vessels to be designed for a pressure of a few inches of water rather than 30 psig.

This approach relies on effective CIP to keep competitive organisms at bay, and uses sterilization as backup in the event of CIP failure. Even then, conventional steam sterilization is not an option, as the design pressure and vacuum rating of the equipment is less than 1 psig. To accommodate this design pressure limitation, sterilization is done using modified steam sterilization techniques or using other sterilants instead of steam.

Carrying out steam sterilization at atmospheric pressure is one way to modify steam sterilization. All the steps mentioned above would still be followed, but instead of 250°F, the vessel surfaces will only reach 212°F. This will result in a significantly longer hold period, which will have to be established based on experience. Given the design pressure of these vessels, providing adequate pressure and vacuum relief is of utmost importance, especially the latter. At this time, the only available choice for pressure and vacuum relief for these large vessels is to use pressure-vacuum-vent valves (also referred to as conservation vents) that are designed for atmospheric storage tanks. Since these are available only up to 12-in.-dia. size, depending on the size of the vessel, multiple relief valves may be required.

Chemical sterilization is an alternative to steam sterilization, and this approach gets around the problem of dealing with vacuum conditions that arise during steam condensation. There are a number of chemicals that can be used as sterilants; some of the most commonly used are discussed below.

Chlorine dioxide. Chlorine dioxide (ClO_2) is an oxidizing agent. In its gaseous form, it is registered as a sterilant for manufacturing and processing equipment, surfaces, tools and cleanrooms. It is a yellow to greenish-yellow gas that must be generated onsite. Chlorine dioxide generators are commercially available and they typically produce ClO_2 by flowing dilute chlorine gas through sodium chlorite canisters. Chlorine dioxide can be explosive at concentrations above 10 vol.% in air, so it is important to keep its concentration safely below that. ClO_2 concentrations required for sterilization are on the order of 1 mg/L.

After the desired concentration is achieved, the vessel is held at this concentration for 1–2 h, the exact time to be based on experience. The last step is to remove the ClO_2, which is accomplished by displacing it with sterile, filtered air. ClO_2 has been used to sterilize bulk aseptic storage tanks, such as orange juice storage tanks, but to date, there are no reports of it being used in bioprocess facilities.

Peracetic acid. Peracetic acid ($C_2H_4O_3$) is usually available as a mixture of acetic acid (CH_3COOH) and hydrogen peroxide (H_2O_2) in water. It is a colorless liquid that has a pungent odor and a low pH value. Peracetic acid is produced by a reaction between hydrogen peroxide and water. It is an oxidizing biocide, which is widely used to sterilize medical, surgical and dental instruments.

It is also approved for use in the direct disinfection of fruits and vegetables. But the use of peracetic acid as a hard surface disinfectant is of interest here. Commercial formulations typically contain 5–6% peracetic acid, 7–10% acetic acid, and 21–27% hydrogen peroxide, and are used in low concentrations to disperse and penetrate biofilms.

They are effective against bacteria, mold, fungus and yeast. These formulations, diluted to 200 ppm in water, can be used as a sanitizing rinse at the conclusion of the CIP process. No water rinse is required after peracetic acid sanitization, and this agent will not corrode stainless steel.

Hydrogen peroxide vapor (HPV). HPV sterilization technology is used primarily in the pharmaceutical industry for bio-decontamination of isolators, freeze dryers, incubators and laboratory or production rooms. HPV is effective against a wide variety of microorganisms including fungi, bacteria and viruses. To date, there are no reports of HPV being used for sterilization or sanitization of very large-scale process systems.

To make HPV work, one would have to generate HPV onsite by flash-evaporating 30–35 wt.% hydrogen peroxide. Currently, commercially available HPV generators are too small to generate sufficient quantities of HPV to carry out sterilization of very large systems in a reasonable time period.

A major attraction of HPV sterilization is that there are no wastes to treat from this process, as the peroxide decomposes to oxygen and water vapor.

In the foregoing discussion, we have used the terms sterilization and sanitization somewhat interchangeably. Sterilization means destruction of all organisms and that means that most or nearly all organisms are killed.

However, as mentioned below, such high standards are generally not required during the production of large-scale biofuels or biochemicals. A low-cost sanitization technique that is capable of keeping biocontaminants at an acceptable level may be all that is required. Of the techniques mentioned above, one of them — sanitization with peracetic acid — is the easiest to implement via the CIP system.

Closing thoughts

The current relatively low price of petroleum has dampened some of the enthusiasm for building large-scale biofuel- and biochemical-production facilities. However, ongoing concern about climate change and sustainability will eventually lead to more of these facilities being built. Hygienic design considerations are critical to the reliable operation of these facilities, and implementation of hygienic design in a cost-effective manner will be a major factor in ensuring success of industrial-scale fermentation for the production of biobased chemicals. ■

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Process Safety and Functional Safety in Support of Asset Productivity and Integrity

Approaches to plant safety continue to evolve based on lessons learned, as well as new automation standards and technology

Luis Durán
ABB Process Automation Control Technologies

In the chemical process industries (CPI), one incident can have a tremendous impact on the people in the plant, the communities around it, the environment and the production asset.

This article outlines how learning from past incidents continues to drive the development of both newer standards, as well as new approaches to process automation as it relates to plant safety and security.

FIGURE 1. Safety should always a priority at a process plant

Learning from incidents

Today, there is a lot of information available about process incidents and industrial accidents from sources such as the Chemical Safety Board (www.csb.gov), Industrial Safety and Security Source (www.isssource.com) or Anatomy of an Incident (www.anatomyofanincident.com). Regardless of the source, and considering the amount of public discussion that takes place, particularly following the very large and visible industrial incidents, it's important to take the opportunity to learn and seek opportunities to improve and prevent these incidents from happening again (Figure 1).

The impact of incidents and accidents on people, the environment and plant assets is significant. According to a Marsh LLC (www.marsh.com) publication [*1*], there is evidence that the petrochemical sector suffered a terrible period in terms of accidents between 1987 and 1991 (Figure 2). The losses (property damage of the production assets, liabilities and so on), recorded in that period were about ten times worse than previous periods (1976–1986) and about 3.5 times worse than following periods (1992–2011).

On the positive side, the Marsh report shows that there has been improvement in the sector after 1992. This improved safety can be attributed, in part, to the introduction of the process safety management (PSM) standards.

Taking a closer look, it is evident that the significant loss for the 1987 –1991 period was dominated by three explosion events, two of which were vapor-cloud explosions and account for 70% of the total losses for this timeframe. The key takeaway from this is that a single incident can have a tremendous impact on the people in the plant, the communities around it, the environment and, last but not least, the production asset.

In 1992, the U.S. Occupational Safety and Health Administration (OSHA; www.osha.gov) — the agency tasked with safety of personnel — issued the Process Safety Management of Highly Hazardous Chemicals standard (29 CFR 1910.199). This regulation set a requirement for hazard management and established a comprehensive PSM program that integrates technology, procedures and management practices. The introduction of this standard may be credited with improving process safety performance in U.S. hydrocarbon processing facilities.

Defining safety

In industry, safety is defined as a reduction of existing risk to a tolerable or manageable level; understanding risk as the probability of occurrence for that harmful incident and the magnitude of the potential harm. In

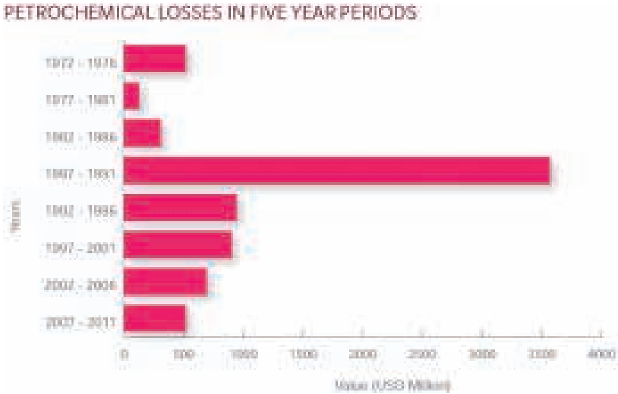

FIGURE 2. The 1987–1992 period was exceptionally bad for the petrochemical sector due to a few major accidents (Source: Marsh LLC [*1*])

FIGURE 3. Operators at a modern control room monitor both the operation of the process as well as the safety and security of the plant

many cases, safety is not the elimination of risk, which could be impractical or unfeasible.

Although the CPI must accept some degree of risk, that risk needs to be managed to an acceptable level; which in turn makes safety a societal term as well as an engineering term. Society establishes what is commonly accepted as safe and engineers have to manage risk by introducing risk-reduction methods including human elements, such as company culture and work processes and technologies that make the production facilities an acceptable place to work and a responsible neighbor in our communities.

The CPI has applied learnings from numerous events over the last 40 years. These incidents and accidents have resulted in changes to regulations and legislation and have driven the adoption of best practices that address the known factors at the root of those events.

A lot of the best practices are related to understanding and evaluating hazards and defining the appropriate risk reduction, including measuring the effectiveness of the methodologies or technologies used in reducing the risk.

Risk-reduction methods using technology — including digital systems — have received extensive coverage in trade publications over time as they are important contributors to process safety and plant productivity. However, it is critical to recognize human factors and their impact on process safety in the design, selection, implementation and operation of technology.

Connecting PSM and FS

Organizations, such as OSHA, recognize Functional Safety Standard ISA 84 as a Recognized and Generally Accepted Good Engineering Practice (RAGAGEP) and one way to meet the PSM requirements defined in 29 CFR 1910.199. Applying ISA 84 is more than purchasing a technology with a given certification or using a particular technology scheme or architecture. Industry best practices such as ISA 84 consider a great deal of applied learning. ISA 84 is a performance-based standard and describes multiple steps before and after selecting and implementing safety system technologies. These steps — commonly referred to as the safety lifecycle — are also the result of applying lessons learned from incidents and events.

Research (as documented in the book "Out of Control" [*2*]) has shown that many industrial accidents have their root cause in poor specification or inadequate design (about 58%). Additionally, users should consider that installing a system is not the "end of the road," but rather another step in the lifecycle of the facility. Approximately 21% of incidents are associated with changes after the process is running, and about 15% occur during operation and maintenance.

ISA 84's grandfather clause

It is well-known that Functional Safety Standard ISA 84.01-2004 contains a grandfather clause based on OSHA regulation 1910.119. This clause allows users to continue the use of pre-existing safety instrumented systems (SIS) that were designed following a previous RAGAGEP, and to effectively keep its older equipment as long as the company has determined that the equipment is designed, maintained, inspected, tested and operated in a safe manner. As indicated by Klein [*3*], that does not mean that the existing system can be grandfathered and ignored from that point forward.

The intent of the clause is for the user to determine if the PSM-covered equipment, which was designed and constructed to comply with codes, standards or practices no longer in general use, can continue to operate in a safe manner, and to document the findings. Therefore, the emphasis should be on the second part of the clause, which states that "the owner/operator shall determine that the equipment is designed, maintained, inspected, tested and operated in a safe manner." And that determination is a continuous effort that should be periodically revised until said equipment is removed from operation and replaced with a system that is designed in line with current best practices.

Another consideration is that the clause would cover not only hardware and software, but also management and documentation, including maintenance, all of which should follow current standards — that is, the most recent version of ISA 84 or IEC 61511.

Emerging technologies

The last few decades have seen technology changing in all aspects

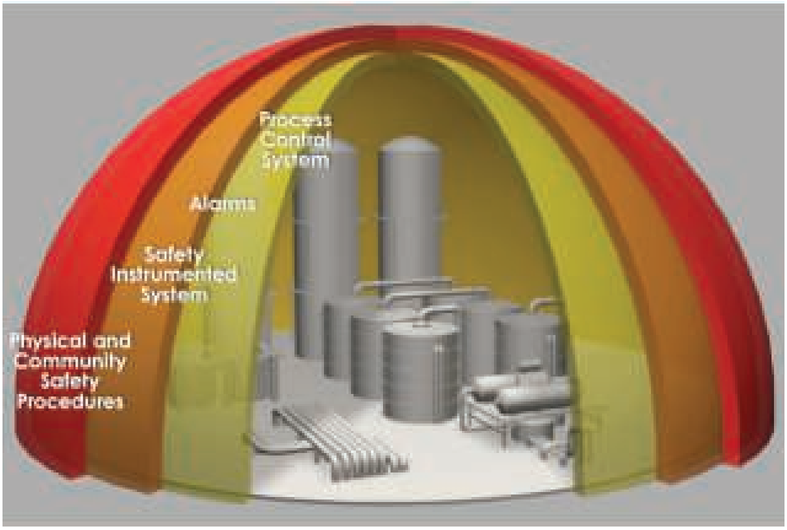

FIGURE 4. This diagram illustrates the concept of functionally independent protection layers

of humankind's daily activities. Process automation and safety automation have not escaped from such changes (Figure 3). Nevertheless, technology-selection criteria should respond to the risk-reduction needs in the manufacturing facility and consider the improvements that some of these technologies offer, such as enabling better visualization of the health of the production asset.

The new breed of systems not only addresses the need to protect plant assets, but allows users to bring safety to the center stage, side by side with the productivity of the plant, in many cases by eliminating technology gateways and interfaces that were common a few years ago.

There are also new developments, particularly in software, that help prevent human errors in the design, and that guide users to fulfill industry best practices using standard off-the-shelf functionality. Off-the-shelf products avoid the introduction of error by complex manual programming and configuration.

Although productivity and profitability of many manufacturing processes limit the rate of change in the process sector, whenever there is an opportunity, facilities should explore modern technologies and determine if they are a good fit. One should not assume the system shouldn't be touched behind the shield of "grandfather clauses" that are believed to justify maintaining the system "as-is." Once again, despite the comfort provided by known technologies, such as general-purpose programmable logic controlers (PLCs), it is important to keep in mind that those platforms might not satisfy the current risk-reduction requirements in the facility and a significant investment to maintain the risk-reduction performance over the lifecycle of the plant asset micht might be required. Also, users will need to develop new competencies in order to understand new risk-reduction requirements and apply the next generation of technology accordingly.

Performance-based safety standards (IEC 61508 and IEC 61511/ISA 84) have changed the way safety systems should be selected. The days of simply choosing a certified product, or selecting a preferred technology architecture should be behind us; today's system selection is driven by performance requirements and the risk-reduction needs of the plant.

Understand the hazards

Although this has nothing to do with the safety system technology, it is critical in the selection process to understand the scope of the process hazards and to determine the necessary risk reduction required. This should be done to create the safety requirements specification (SRS) necessary to start a system selection. Even when replacing an existing system, this is critical because the risk profile of the plant may have changed since installation.

Potential common-cause failures

There has been a long-standing requirement that a safety system must be different (or diverse) technology from its process-automation counterpart to avoid common-cause failures. But most safety systems rely on component redundancy (hardware fault tolerance [HFT]) to meet reliability and availability requirements, introducing a degree of common-cause failure directly into the safety system. Rather than redundancy, modern systems now provide a diversity of technologies designed into logic solvers and input/output (I/O) modules, along with a high degree of diagnostics, to allow a simplex hardware configuration to meet safety integrity level (SIL) 3 requirements.

Product-implementation diversity is also key. Even though most safety systems are manufactured by process-automation vendors, organizational diversity between the two product teams is only the first level of separation. Within the safety product team, leading suppliers will also be separating the design group from product-development group and then again from the product-testing group.

Systematic capabilities

Systematic capabilities address how much protection against human factors is built into the safety system. Users should look for the following:

- Certified software libraries that offer functions according to the SIL requirements of the application
- Compiler restrictions to enforce implementations according to the SIL requirements
- User-security management to separate approved from non-approved users for overrides, bypass and other key functions
- Audit-trail capability to record and document changes to aid in compliance with functional safety standards

Separate, interfaced or integrated

Typically based on the SRS and other business needs, it is important to define one of these three integration philosophies. Integrated systems offer many key benefits, drawing on common capabilities of the process automation system not related to

FIGURE 5. Integrated control and safety is a modern alternative to traditional point solutions

the safety functions directly. But only being interfaced or even kept completely separate are also options, and need to be thoroughly considered.

Protection layers

The use of multiple protection layers, or functionally independent protection layers (Figure 4) to be precise, is common in industry. These include technology elements such as the process control system and alarms. Safety instrumented systems are a last resort to prevent a hazard from escalating.

There are additional layers that mitigate the impact of a hazard or contain it. Once more, there are other layers of protection that are not based on technology, but on work processes or procedures that might be even more critical than the technology in use.

Most times, system interfaces are not designed, implemented or tested in accordance to industry best practices or current functional safety standards, and therefore they have an impact on the performance of the system. It has been common to ignore safety requirements on these interfaces. Failure of these interfaces should not compromise the safety system.

Integrated control and safety (Figure 5) is a modern alternative to previous point solutions that takes into consideration the best practices and solves issues related to interface design, implementation and maintenance, both in compliance to functional safety standards and at a lower cost over the lifecycle.

Network security

The extended use of networked systems is also territory for potential vulnerabilities. A lot of ground has been covered in this area over the last five years and industry has experienced the emergence of standards to address new threats and has the accelerated development of a strong relationship between safety and security. To satisfy the security requirements of a system network, the user should do the following:

- Perform a full vulnerability assessment/threat modeling and testing of the different subsystems
- Define the best security mechanism for each of those subsystems to cover any identified gaps
- Perform a full vulnerability assessment/threat modeling and testing of the entire interfaced architecture

For users of an interfaced system, which could be "secured" using "airgaps," the key is establishing a security management system (SMS) of the interface architecture and supporting it over the system lifecycle.

Defense-in-depth in security

The principle of "defense in depth" (Figure 6) means creating multiple independent and redundant prevention and detection measures. The security measures should be layered, in multiple places, and diversified. This reduces the risk that the system is compromised if one security measure fails or is circumvented. Defense-in-depth tactics can be found throughout the SD3 + C security framework (secure by design, secure by default, secure in deployment, and communications).

Examples of defense-in-depth tactics include the following:

- Establishing defenses for the perimeter, network, host, application and data
- Security policies and procedures
- Intrusion detection
- Firewalls and malware protection
- User authentication & authorization
- Physical security

The key message is that, like in the case of safety, security is not resolved only by certification and it's not an isolated activity after the product development is completed. Security is part of the design considerations early in the process and must be supported over the site lifecycle.

Summary

Although following the functional safety standards is not a silver bullet, it's a good place to start the journey to improve safety in the process sector. If your industry requires compliance to OSHA regulation 1910.119, for the automation portion of any project, complying with the requirements of ISA 84 is a way to address PSM requirements.

Adopting ISA 84 is more than selecting a certified or SIL-capable logic solver or having a given redundancy scheme on the instrumentation. It requires a lifecycle approach that starts with the hazards analysis and defines the required risk reduction. It also involves evaluating technologies that better address the hazards and reduce the risk, as well as considering the technical requirements to mitigate risk to an acceptable level.

Although existing systems can be grandfathered, they can't be ignored from that point forward. Rather, it is a continuous effort that should be periodically revised until the equipment is removed from operation and replaced with a system designed following current best practices.

When it's time for selecting a new risk-reduction technology, consider that choosing a given technology scheme is not enough to address the

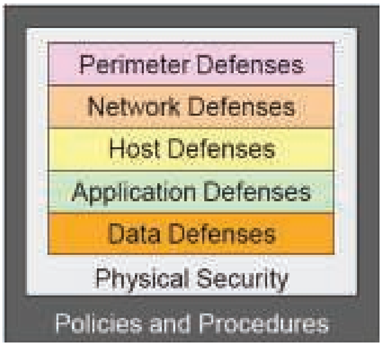

FIGURE 6. The concept of "defense in depth in security" is illustrated here

functional safety requirements. Assuming that your existing technology or a "replacement in kind" still complies with the safety requirements of your process might lead to a "false sense of safety." Consider the new breed of systems that not only addresses the need of protecting the plant assets, but allows users to bring safety to the center stage side to side with the productivity of the plant — in many cases by eliminating technology gateways and interfaces that were common a few years ago, therefore also reducing lifecycle cost and maintenance efforts.

The selection criteria should begin with a proper understanding of the hazards and a technology assessment to address human factors, avoidance of common factors that could disable the safety instrumented system, and the integration of process safety information to the process automation systems; this integration is possible and must be done right.

Like in the case of safety, security (or network security) is not resolved only by certification and it's not an isolated activity after the product development is completed but part of the design considerations early in the process and that must be supported over the site lifecycle. ■

Edited by Gerald Ondrey

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2013 ▬ 2014 ▬ 2015 ▬

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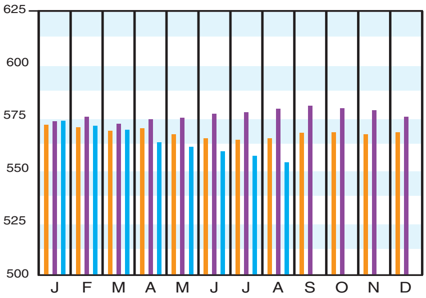
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Aug. '15 Prelim.	Jul. '15 Final	Aug. '14 Final
CE Index	553.4	556.3	578.7
Equipment	664.9	669.7	703.7
Heat exchangers & tanks	592.2	597.9	648.7
Process machinery	657.5	658.5	668.0
Pipe, valves & fittings	822.3	829.1	877.1
Process instruments	391.1	394.7	413.9
Pumps & compressors	956.5	956.5	939.3
Electrical equipment	509.8	512.5	516.3
Structural supports & misc	731.3	737.7	773.7
Construction labor	323.4	321.6	320.4
Buildings	540.7	541.8	545.3
Engineering & supervision	318.7	318.5	320.3

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

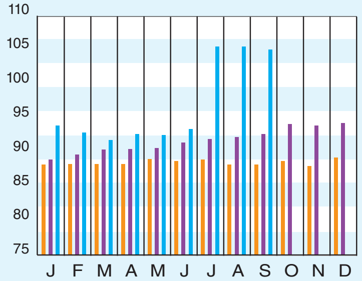
Annual Index:
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1



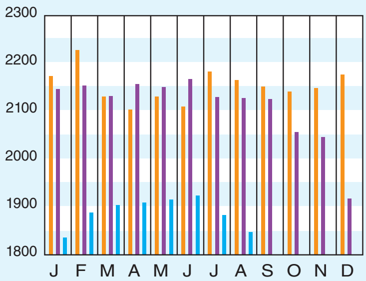
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2012 = 100)	Sept. '15 = 105.0	Aug.'15 = 105.1	July'15 = 105.6	Sept. '14 = 104.3
CPI value of output, $ billions	Aug.'15 = 1,847.1	July '15 = 1,879.9	June'15 = 1,923.0	Aug. '14 = 2,151.0
CPI operating rate, %	Sept. '15 = 75.8	Aug.'15 = 75.9	July'15 = 76.4	Sept. '14 = 75.8
Producer prices, industrial chemicals (1982 = 100)	Sept. '15 = 238.1	Aug.'15 = 249.1	July'15 = 247.3	Sept. '14 = 293.1
Industrial Production in Manufacturing (2012=100)*	Sept. '15 = 105.5	Aug.'15 = 105.7	July'15 = 106.1	Sept. '14 = 104.1
Hourly earnings index, chemical & allied products (1992 = 100)	Sept. '15 = 160.3	Aug.'15 = 158.6	July'15 = 159.1	Sept. '14 = 157.0
Productivity index, chemicals & allied products (1992 = 100)#	Sept. '15 = 108.1	Aug.'15 = 107.3	July'15 = 107.9	Sept. '14 = 106.1

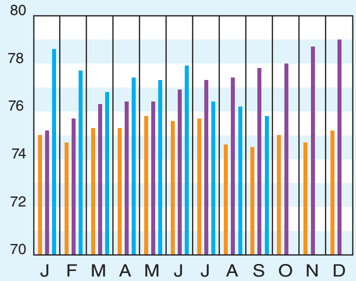
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
#Correction: The values for the Productivity Index published in the September and October issues of *Chem. Eng.* were not correct due to the omission of an adjustment factor. The correct value for the July Productivity Index in the September issue should have been reported as 106.9, and the correct value for the August Productivity Index (October issue) should have been 107.3. We apologize for any confusion.
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the August 2015 *CE* Plant Cost Index (CEPCI; top; the most recent available) fell compared to the previous month's value, driven by declines in the Equipment and Buildings subindices. The Construction Labor and Engineering & Supervision subindices rose slightly in the preliminary August numbers. The August CEPCI value is 4.3% lower than the corresponding value from a year ago at the same time. This represents a continued increase in the year-to-year differential over the past several months. Meanwhile, the latest Current Business Indicators (CBI; middle) numbers showed a minuscule drop in the CPI output index in September along with a dip in producer prices.