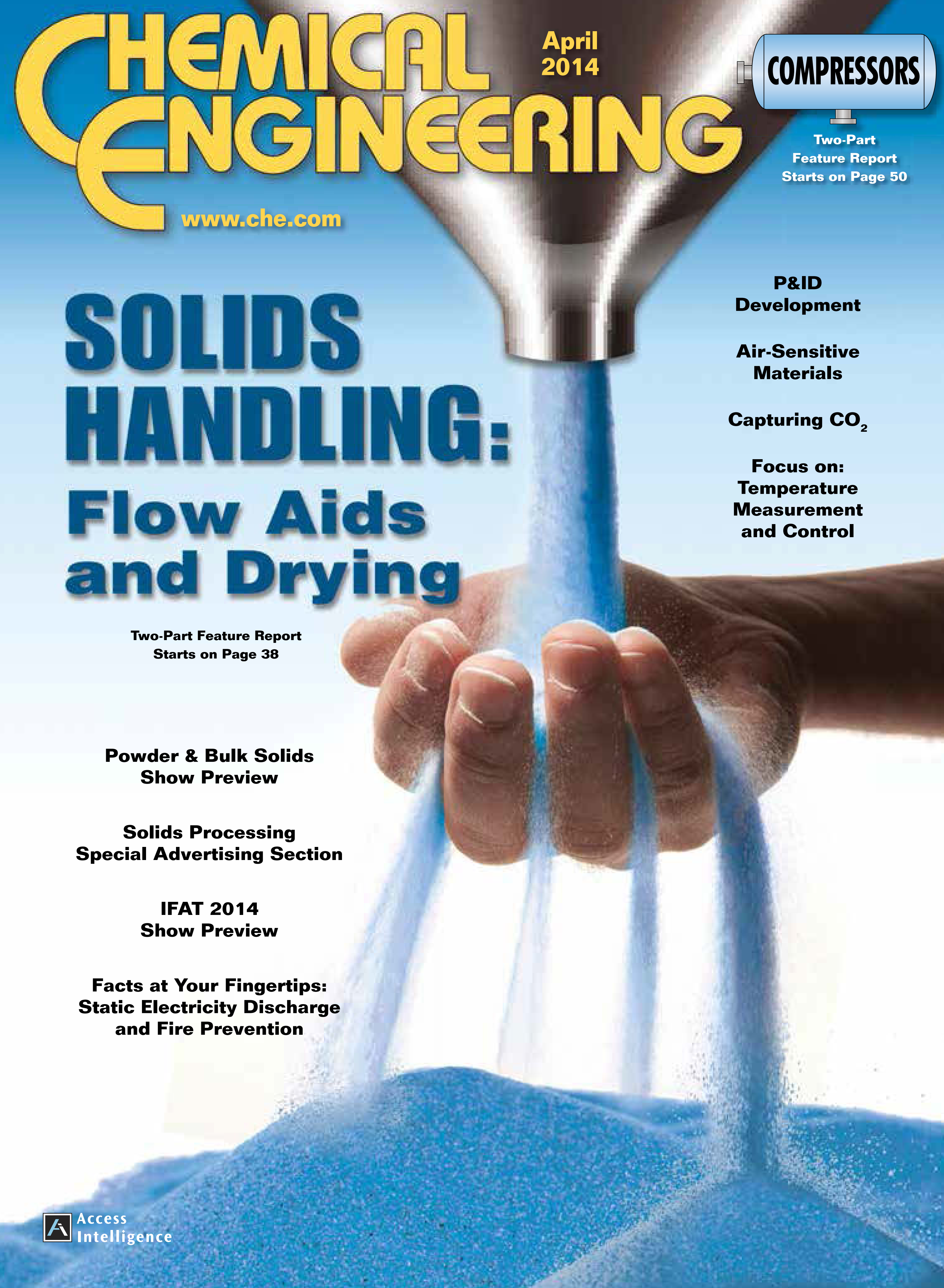

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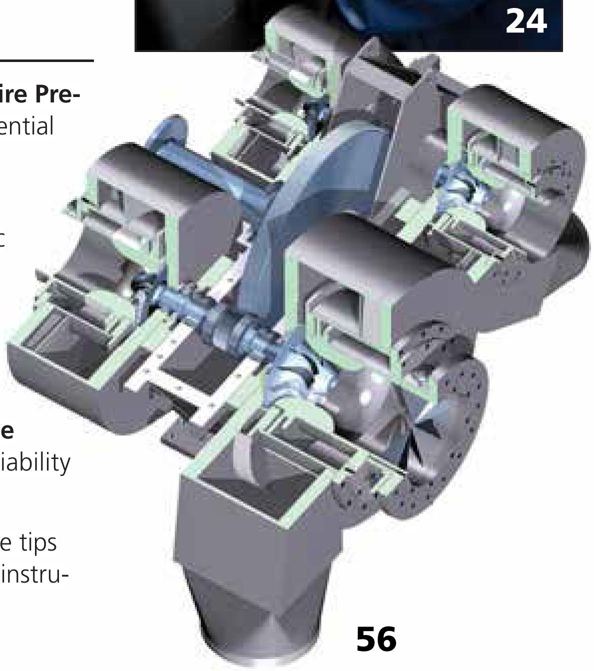

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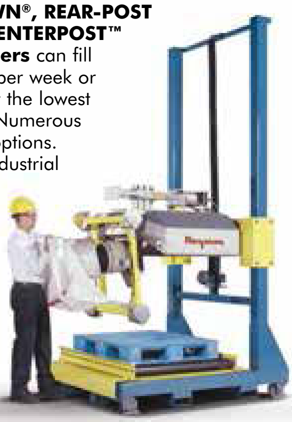

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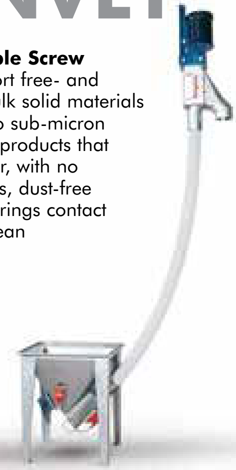

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BPA

Editor's Page

Cybersecurity: The challenges of interconnectivity

Big-time security threats and breaches, like the recent Target data breach involving confidential consumer information, remind us of how vulnerable our interconnectivity makes us. And yet, the advantages of the technological advances that we enjoy are so many that there is no turning back.

In his keynote presentation at the recent ARC Industry Forum (February 2014; Orlando, Fla.; www.arc.com), ARC Advisory Group president Andy Chatha described how intelligent assets, devices, sensors, data communication platforms, analytics and software are already in place, and form the building blocks for the industrial Internet of Things (IoT) — a term that is now commonly used to refer to the network connectivity of objects. Chatha cited the multitude of capabilities that are now being built into automobiles as an example of how our world is increasingly interconnected through technology. He predicts that this year will see a breakthrough in wearable devices, such as those already available for monitoring health.

The advantages of interconnectivity in an industrial setting can be many, for example: enabling better performance through predictive maintenance; remote monitoring and fixes; better field-service capabilities through mobile devices; and for platforms, such as cloud computing, cost savings by being able to pay for only what you use.

Along with the advantages comes a number of challenges, such as an increase in complexity. As one ARC Forum participant noted, things have become so complex these days that it can be a challenge to figure out how to operate a car when you rent one — sometimes even how to turn it on is not obvious. But for industrial IoT, Chatha says that "Cybersecurity is by far the biggest challenge."

One part of this challenge is that the "fixes" to maintain cybersecurity are continuously evolving as the threats advance. A milestone in addressing the cybersecurity challenge was the release, on February 12, of the U.S. Cybersecurity Framework (www.nist.gov/cyberframework). The intention is for the Framework to be a living document that will be updated as industry provides feedback. The Cybersecurity Framework is the result of partnership efforts among The White House, the Automation Federation and its founding organization, the International Society of Automation (ISA; Research Triangle Park, N. C.; www.isa.org). In fact, the ISA's industrial automation and control system (IACS) security standards (ISA99/IEC63443) are among the framework's recommendations.

But even with guidelines, the challenges faced by industry are many. In a survey of end users conducted by the ARC Advisory Group and reported by Sid Snitkin (vice president and general manager of Enterprise Advisory Services), major hurdles to industrial control system (ICS) security include a lack of understanding of the difference between cybersecurity for IT and for ICSs, and the lack of resources with the needed cybersecurity expertise. These issues, among others, were discussed during an ARC Forum panel on the topic. While there are no easy answers, two strong messages that came across are the following: (1) both IT and ICS experts need to work together on industrial cybersecurity; and (2) maintaining security is hard work that requires great diligence on the part of the user. ■

Dorothy Lozowski, Editor in Chief

Letters

Honors for commercialization of scientific innovations

In an effort to acknowledge great scientific achievements each year, the Industrial Research Institute (IRI) — an association that brings together leading practitioners in technological innovation and R&D management to seek, share, learn and create best practices — recognizes the invaluable contribution of individual innovators to the advancement of science, industry and society with its presentation of the IRI Medal.

For the commercialization of scientific innovations in areas ranging from plastics manufacturing to nanomedicine, which demonstrate significant economic, environmental, and societal impact, IRI is awarding this year's medal to Dr. Joseph DeSimone, the Chancellor's Eminent Professor of Chemistry at the University of North Carolina (UNC) at Chapel Hill and William R. Kenan, Jr. Distinguished Professor of Chemical Engineering at North Carolina State University and of Chemistry at UNC.

DeSimone is a polymer chemist who has aided breakthroughs in fluoropolymer synthesis, colloid science, nano-biomaterials, green chemistry and most recently, 3-D printing. He holds 140 patents, with over 80 patents pending, and has published over 300 scientific articles. He received a B.S. in chemistry from Ursinus College in 1986 and a Ph.D. in chemistry from Virginia Tech in 1990.

The award ceremony for Dr. DeSimone is on the evening of May 21, 2014, at the Sheraton Boston Hotel during IRI's Annual Meeting.

IRI is an organization of more than 200 industrial and service companies having a common interest in the effective management of technological innovation.

The Industrial Research Institute
Arlington, Va.; www.iriweb.org

Postscripts, corrections

January 2014, "Propylene Production via Propane Dehydrogenation," p. 27. In the January Technology Profile, an error was made in printing the assumptions for the economic analysis. The issue states the analysis is based on a plant with a capacity of 590 ton/yr. It should have said a 590,000 ton/yr capacity.

The corrected version of the full article can be found at www.che.com. ■

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IW Best Plants 2014. Manufacturing Enterprise Solutions Assn. (MESA) International (Chandler, Ariz.) and Industry Week. Phone: 216-931-9512; Web: iwbestplants.com
Milwaukee, Wisc. **May 5–7**

Battcon 2014 — International Stationary Battery Conference and Trade Show. Albercorp/Battcon (Pompano Beach, Fla.). Phone: 800-851-4632; Web: battcon.com
Boca Raton, Fla. **May 5–7**

PTXi Powder and Bulk Solids 2014. UBM Canon (Los Angeles, Calif.). Phone: 310-445-4200; Web: powdershow.com
Rosemont, Ill. **May 6–8**

Identify, Characterize, Select and Isolate the Optimal Solid State Form for Pharmaceutical Development. Scientific Update (East Sussex, U.K.), in conjunction with Crystal Pharmatech (Princeton, N.J.) and Rutgers University (New Brunswick, N.J.). Phone: +44-1435-873062; Web: scientificupdate.co.uk
Rosemont, Ill. **May 6–8**

ESTECH 2014 — 60th Annual Technical Meeting and Expo of IEST. Inst. of Environmental Sciences and Technology (IEST; Arlington Heights, Ill.). Phone: 847-981-0100; Web: iest.org
San Antonio, Tex. **May 13–16**

Residuals and Biosolids 2014. Water Environment Federation Specialty Conferences (Alexandria, Va.). Phone: 800-666-0206; Web: wef.org
Austin, Tex. **May 18–21**

Refinery & Petrochemical Wastewater Treatment Training. Refinery Water Engineering & Assoc. (Nederland, Tex.) and Lamar University (Beaumont, Tex.). Phone: 409-332-4040; Web: refinerywater.org/beaumont-texas-june-2014
Arlington Heights, Ill. **June 3–4**

14th Annual AWMA Conference. Air & Waste Management Assn. (Pittsburgh, Pa.). Phone: 412-232-3444; Web: awma.org
Long Beach, Calif. **June 24–27**

Establishing and Monitoring a Clean Manufacturing Program. Institute of Environmental Sciences and Technology (Arlington Heights, Ill.). Phone: 847-981-0100, Ext. 6012; Web: iest.org
Arlington Heights, Ill. **July 16**

2014 Chemical Sector Safety Security Summit and Expo. SOCMA (Washington, D.C.). Phone: 202-721-4100; Web: socma.com
Baltimore, Md. **July 22–24**

Gasification Technologies Conference 2014. Gasification Technologies Council (Arlington, Va.). Phone: 703-276-0110; Web: gasification.org
Washington, D.C. **Oct. 26–29**

EUROPE

IFAT 2014: Trade Fair for Water, Sewage and Waste Management. Messe München GmbH (Munich, Germany). Phone: +49-89-949-21478; Web: ifat.de
Munich, Germany **May 5–6**

22nd Annual European Biomass Conference and Exhibition. ETA Florence (Florence, Italy). Phone: +39-55-5002280, Ext. 221; Web: conference-biomass.com
Hamburg, Germany **June 23–26**

PEPP 2014: 22nd Annual Polyethylene-Polypropylene Chain Technology and Business Forum. IHS Chemical (Englewood, Colo.). Phone: 512-582-2015; Web: ihs.com/pepp2014
Zurich, Switzerland **June 25–26**

Nanofair 2014. VDI Wissensforum GmbH (Düsseldorf, Germany). Phone: +49-351-83391-3317; Web: nanofair.com
Dresden, Germany **July 1–3**

10th European Soc. of Biochemical Engineering Sciences and 6th International Forum on Industrial Bioprocesses. University of Lille (Lille, France), in collaboration with the American Chemical Soc. (Washington, D.C.). Fax: +33-3-2876-7356; Web: esbes-ifibiop-lille2014.com
Lille, France **Sept. 7–10**

IWA World Water Congress 2014. IWA Exhibition Management (The Hague, The Netherlands). Phone: +31-70-382-0028; Web: iwa2014lisbon.org
Lisbon, Portugal **Sept. 21–26**

ICBR 2014: 19th International Congress for Battery Recycling. ICM AG (Birrwil, Switzerland). Phone: +41-62-785-1000; Web: icm.ch
Hamburg, Germany **Sept. 24–26**

ASIA & ELSEWHERE

Interpack Fair Recycling Conference. Plastics Recyclers Europe (Brussels, Belgium). Phone: +32-2-742-96-82; Web: plasticsrecyclers.eu
Düsseldorf, Germany **May 8**

InaChem. Federation of the Indonesian Chemical Industry (Jakarta, Indonesia), Indonesian Institution of Chemical Engineers, and Ministry of Industry of Indonesia. Phone: +62-21-789-2938; Web: ina-chem.com
Jakarta, Indonesia **Aug. 14–16** ■

Suzanne Shelley

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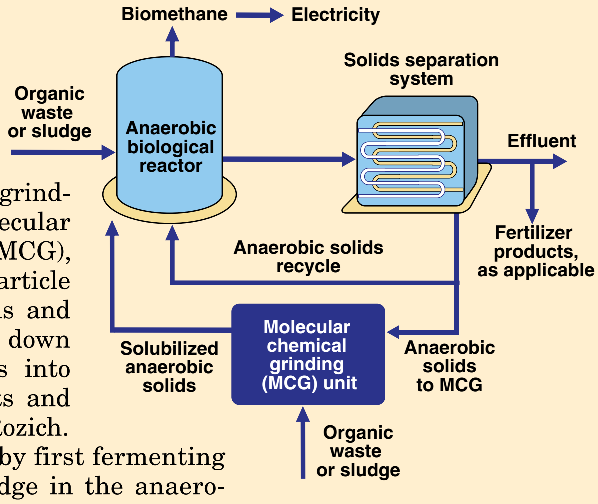
Edited by Gerald Ondrey April 2014



An organic waste-to-biogas system to be scaled up in first installation

Construction will soon begin at a site in Korea on an anaerobic digester technology that converts organic waste and biomass to methane at high conversion rates, while also producing a fertilizer stream. Technology developer Bioconversions Solutions LLC (Exton, Pa.; www.bioconversionssolutions.com) announced that this first large-scale facility in Korea will be followed by a second in Australia in 2015.

Known as AFC_2 (Advanced Fluidized Co-Digestion & Co-Generation), the technology uses naturally occurring anaerobic bacteria to convert a variety of organic wastes and biomass to methane by fermentation, for use in power generation. At the same time, the process removes nitrogen, phosphorus and potassium nutrients that can be used as agricultural fertilizer.

The digester operates at between 90 and 105°F and is capable of converting up to 90% of waste solids into biogas, says Bioconversions CEO Al Rozich. A key to the high conversion rates is a particle-size reduction technique developed by the company that increases the digestibility of the organic material. The technique involves nano-grinding units, called Molecular Chemical Grinding (MCG), which reduce the particle size of solid materials and selectively break down large macromolecules into smaller polymer units and monomers, explains Rozich.

The process works by first fermenting organic waste or sludge in the anaerobic bioreactor, where biomethane is removed for electrical power generation. The remaining solids are sent to the MCG unit, where they are broken down, solubilized and sent back to the reactor for further digestion. The process also has a separation system that removes the fertilizer products.

"The process features low operating costs, and can reduce the amount of solids requiring disposal to very low levels," Rozich says. The first large-scale installation of the AFC_2 technology is at a municipal wastewater facility in Daejeon, South Korea, where the goals include minimizing sludge production and associated costs at the plant.

A promising process to recover Li from seawater

Lithium is an element of growing importance for the production of batteries and nuclear fuels. Because Japan relies completely on imports of this material, with the majority coming from South America, the country is looking for alternative sources for this element. The answer may be in the island-nation's own "backyard" — namely, seawater. A promising, "revolutionary" technology, which recovers lithium from seawater while simultaneously generating electricity, is being developed by Takeshi Hoshino and colleagues at the Japanese Atomic Energy Agency (JAEA; Aomori; https://www.jaea.go.jp).

The process uses electrodialysis with an ionic-liquid film as the separator between the cathode and anode. As seawater flows through the anode side of the electrodialysis cell, only Li^+ ions are able to pass through the ionic liquid, thus forming a concentrated Li^+ solution on the cathode side.

In the laboratory, using a Nasicon-type crystalline ceramic as a support for the ionic liquid, the researchers have demonstrated the ability to recover 7% of the Li^+ from 25 L of seawater after 3 days, while generating electricity (0.04 V, 0.1 mA). After 30 d, a 50% recovery was achieved from a brine solution (Li^+ concentration 50–100 times higher than seawater). The lithium is subsequently recovered as purified Li_2CO_3 after precipitation with Na_2CO_3, filtration and drying.

The researchers are planning to build a pilot plant to further develop the technology, which may also be suitable for recycling lithium from batteries, and recovering lithium and other minerals from desalination brine.

Ammonia synthesis

Last month, Haldor Topsøe A/S (Lyngby, Denmark; www.topsoe.com) introduced a new ammonia-synthesis catalyst. Tradenamed KM 111, the new catalyst is a magnetite-based catalyst developed for optimal performance in the lower beds of NH_3 converters.

The KM 111 catalyst possesses an activity that surpasses the market-leading activity of KM1, says the company. The increase in activity improves the kinetics of the synthesis reaction, which allows for reductions in temperature — a critical advantage, since chemical equilibrium favors higher conversion at lower temperatures. As a consequence, users who select the combination of KM1 (upper bed) and KM 111 (lower bed) can expect a considerable increase in NH_3 capacity, says Topsøe.

An additional benefit of the higher conversion with KM 111 is a savings in plant operating costs. At existing plants, energy consumption can be reduced by operating at lower loop pressures and lower converter inlet flows with no compromise to production levels. For grassroots plants and for new NH_3 converters at existing plants, KM 111 can meet capacity requirements with a smaller volume of catalyst, allowing users to reduce reactor size.

Note: For more information, circle the 3-digit number on p. 76, or use the website designation.

An inorganic paper for preserving information and other applications

A new kind of highly flexible and non-flammable inorganic paper that can be used for the permanent and safe storage of information has been developed by a team led by professor Ying-Jie Zhu, from the Shanghai Institute of Ceramics, Chinese Academy of Sciences (www.sic.cas.cn). The work has been described in a recent issue of *Chemistry — A European Journal*.

The team developed the paper, which is made from ultra-long nanowires of hydroxyapatite [HAP; $Ca_{10}(OH)_2(PO_4)_6$] — a member of the calcium phosphate family with high biocompatibility and no toxicity. HAP is the major inorganic component of bone and teeth in vertebrates, and is also abundant in seawater.

Various HAP-based materials have been tested for biomedical applications, but they usually exhibit poor flexibility. The team employed a new method for the fabrication of HAP paper. They synthesized ultra-long HAP nanowires with high aspect ratios using calcium oleate, along with its mother reaction solution, as precursor. The amounts of reagents and solvothermal reaction times were varied. The HAP nanostructured materials have readily tunable hydrophilicity/hydrophobicity. The calcium oleate precursor was synthesized by using $CaCl_2$, NaOH, and oleic acid in mixed solvents of ethanol and water at room temperature.

The team found that the ultra-long HAP nanowires can be an ideal raw material for fabricating highly flexible and non-flammable inorganic paper by a simple process of suction filtration. The thickness and area of the paper can be easily tuned by varying the amount of nanowires. The team says the HAP paper has proven very suitable for printing and writing (photo). The paper has also shown excellent performance as an adsorbent for organic pollutants. In addition, this new kind of paper has many other potential uses, such as medical paper, as a drug carrier, bone defect repair, fire-resistant material and high-temperature-resistant material.

This new water-treatment polymer improves scale control in boilers

A newly developed proprietary terpolymer from GE Water and Process Technologies (Trevose, Pa.; www.gewater.com) has been shown to provide improved scale control on heat-transfer surfaces in low- to intermediate- (up to 900 psig) pressure-steam boilers. Deposit formation on heat-transfer and steam-generating surfaces can result in reduced boiler efficiency and tube failures.

Known as Solus AP, the GE material is a random terpolymer of three subunits that are carefully selected for specific chemical functionality, and assembled in a controlled ratio. Solus AP is designed to provide extra forgiveness, in terms of calcium, magnesium and silica scale formation, particularly in boilers where water pretreatment or other systems have failed or are operating sub-optimally.

In addition, Solus AP specifically addresses iron oxide deposition, which is often the dominant contaminant that enters boilers, which are equipped with membrane-based reverse osmosis pretreatment systems, explains Tony Rossi, boiler product manager at GE Water & Process Technologies.

The polymer's anionic functional groups complex with calcium and magnesium cations in solution to prevent scale formation, Rossi says. Simultaneously, Solus AP prevents iron oxide particles from attaching to boiler heat-transfer surfaces, and from coalescing to form larger particles that settle as sludge. This process occurs through a surface-adsorption mechanism. The polymer has been shown to be very efficient at transporting both hardness, iron and silica contaminants through the boiler, says Rossi, so they do not deposit on internal system surfaces.

New electrocoats

A new line of cationic epoxy electrocoats designed by PPG Industries' (Pittsburgh, Pa.; www.ppg.com) industrial coating business unit is launching in North America. In anticipation of upcoming regulatory mandates on heavy metals, these electrocoats feature a proprietary metal-free catalyst. PPG believes the metal-free catalyst it has developed and patented will instill confidence in users, alleviating their concerns about the regulatory issues and price volatility associated with metallic catalysts.

Formulated for low-temperature curing, the electrocoats can cure at temperatures up to 55°F lower than existing cationic epoxy electrocoats, decreasing the energy demands required for their application. With the capability to coat even highly intricate parts, the electrocoats' compatibility with aluminum and alloys is a key factor, as manufacturing trends continue to favor more lightweight construction.

Scratch-resistance

Evonik Industries AG (Essen, Germany; www.evonik.com) has developed an industrial-scale process for producing silane-modified binders for automotive finishes. Prior to this, the production of silane-modified binders has been too complex and expensive for such large-scale applications.

Key to this development is a new process for making silyl isocyanate IPMS or (3-isocyanatopropyl)trimethoxysilane — a critical building block for

(*Continues on p. 14*)

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Imitating nature leads to a separator for oil droplets

Separation of micron-sized oil droplets from water is difficult by conventional methods. A Chinese team has developed an oleophilic array of conical needle structures that can continuously collect micron-sized oil droplets from an oil-water mixture with high efficiency and high throughput. The team includes staff from the Institute of Chemistry of the Chinese Academy of Sciences, Dept. of Chemistry at Tsinghua University, College of Chemistry and Molecular Engineering, Peking University, and the School of Chemistry and Environment, Beihang University (all Beijing; http://ev.buaa.edu.cn). The researchers say the conical needle array could find applications in cleaning up oil spills.

The team's work was inspired from cactus needles, which collect water by condensing moisture from air and directing it to the root of the spines, which keeps the plant hydrated in dry desert environments, says team leader, professor Lei Jiang, of the Academy and Beihang University. To collect oil instead of water, oeleophilic, rather than hydrophilic substances, are used to build conical spikes with a rough surface. "Oil separation using those needle arrays has an efficiency of over 99%," Lei says.

The team fabricated a series of conical copper-based needles from commercial copper wire (0.5-mm dia.), as well as conical needles from polydimethylsiloxane (PDMS). Both materials are oleophilic, but the PDMS is easier to mold. An oil-water mixture (oil droplets <10 μm) is sprayed onto the needles, which were already immersed in water. On the smooth needle, the collected oil droplets grew through frequent coalescence and slowly moved toward the base of the needle. On the rough needle, however, the collected oil droplets could be driven very quickly toward the base of the needle.

(Continued from p. 12)

producing silane-modified binders. Evonik began commercial production of IPMS in a new facility in Marl, Germany since the middle of last year. By combining IPMS with the right additional raw materials, the company can adapt coating binders to the requirements of a given application. The silane group in these binders increases the cross-linking density, making it possible to create automotive finishes that are flexible yet hard, leading to improved scratch resistance, says the company.

Nanoelectrocatalysts

A new class of bimetallic nanocatalysts that are an order of magnitude higher in activity than the 2017 target level set by the U.S. Dept. of Energy (DOE) for fuel cells and electrolyzers has been discovered by researchers at the DOE's Lawrence Berkeley National Laboratory (LBL; Calif.; www.

(Continues on p. 20)

Circle 15 on p. 76 or go to adlinks.che.com/50975-15

A new tantalum line of heat exchangers for corrosive service

Last month, Alfa Laval AB (Lund, Sweden; www.alfalaval.com) introduced a new range of tantalum heat exchangers that offer the corrosion resistance of a solid-tantalum heat exchanger, but at a much lower investment cost. The heat exchangers are made of stainless steel that has undergone a surface treatment whereby a thin layer of tantalum is metallurgically bonded to all surfaces that are exposed to corrosive media. The steel core gives the exchangers high mechanical stability, making them much more resistant to thermal shock than glass, silicon carbide and graphite heat exchangers, says the company.

The new exchangers are based on plate technology. Thanks to a highly turbulent flow, they have a significantly higher thermal efficiency than a shell-and-tube heat exchanger, says the company. The combination of superior flow characteristics with the improved heat-transfer properties of metal enables the new tantalum exchangers to deliver up to 100 times higher thermal efficiency than non-metal shell-and-tube units, says Alfa Laval. As a result, the Alfa Laval TA exchangers have a much smaller footprint than designs based on graphite, glass or silicon carbide, or shell-and-tube ones made of any material (including metals).

The new tantalum range can be used with most corrosive media at temperatures up to 225°C. The exchangers are available with surface areas from 0.58 to 11.2 m^2. Depending on duty, the biggest size can handle a flowrate of up to about 45 m^3/h.

A solid chelating ligand for making heterogeneous catalysts

Shinji Inagaki and colleagues at Toyota Central R&D Labs, Inc. (Nagakute City, Japan; www.tytlabs.com) have synthesized an entirely new immobilization support that can be used to recycle and reuse metalo-organic-complex catalysts, which are widely used for the synthesis of pharmaceuticals and fine chemicals.

Already in 1999, the research group had synthesized the world's first mesoporous organosilica (PMO), which has homogeneous micropores with diameters of 2–30 nm. Now, using a newly synthesized organosilane precursor and a surfactant-directed self-assembly procedure, they succeeded in synthesizing a new, periodic mesoporous organosilica that contain 2,2'-bupyridine (bpy) ligands within the framework (BPy-PMO). The BPy-PMO has a unique pore-wall structure (3.8-nm dia. pores) in which bipyridine groups are densely and regularly packed and exposed on the surface, thus preserving a high coordination ability for metals. By simply dispersing BPy-PMO powder in a solution at 90°C with the desired metal, they were able to prepare various bipyridine-based metal complexes containing Ru, Ir, Re and Pd, after 24 h.

The BPy-PMO showed excellent ligand properties for the direct, heterogeneous Ir-catalyzed borylation of arenes — an important reaction for the one-step synthesis of raw materials for coupling reactions that produce some drugs. The immobilized catalyst showed superior activity, durability, and recyclability compared to the conventional homogeneous Ir catalyst and alternative supports. For instance, a 94% yield was achieved at 80°C after 12 h using the heterogeneous BPy-PMO-supported Ir catalyst. In contrast, a 84% yield was found for the homogeneous (soluble) Ir catalyst, a 63% yield was found for Ir catalyst supported on mesoporous silica, and 33% for Ir catalyst supported on silica gel. The BPy-PMO-supported catalyst can be simply recovered by filtration and dried for reuse. The researchers demonstrated it can be reused up to four times (with the yield dropping to 78%), and less than 1 ppm of Ir remains in the reaction after filtration.

As another example, the group was able to make an efficient photocatalytic system for producing hydrogen by integrating a Ru-complex (as a photo sensitizer) and Pt (as catalyst) onto the pore surface of BPy-PMO. This system requires no "electron relay" molecules.

CO_2-utilizing electrocatalytic reaction cell demonstrated

Production of monoethylene glycol (MEG) from waste carbon dioxide has been validated in a demonstration-scale reaction cell developed by Liquid Light Corp. (Monmouth Junction, N.J.; www.llchemical.com). The company says the catalytic-electrochemistry-technology platform used to make MEG can also produce a range of other important industrial chemicals from CO_2, including isopropanol, acetic acid, methyl methacrylate and others.

The company's recent announcement is an example of the increasing interest in utilizing the greenhouse gas CO_2 as a feedstock for new chemicals (*Chem. Eng.*, July 2013, pp. 16–19).

Liquid Light's core technology is a low-energy catalytic electrochemical reaction cell that operates based on a concept similar to that used in the chlor-alkali process to electrolyze brine solution to make sodium hydroxide and bleach, explains Liquid Light CEO Kyle Teamey.

The company says the reaction cell and overall process are on target for having cost-advantaged economics at large scale for a number of chemicals. For its MEG process, the company estimates the feedstock costs would be 10–20% of existing processes using petroleum, natural gas or corn as feedstocks. MEG has a $27 billion annual market and is used in making consumer products, such as plastic bottles, antifreeze and polyester fabric.

The company has developed several proprietary catalysts for the reaction cell, both homogeneous and heterogeneous, with designs that can be tuned to selectively produce various chemicals. The catalyst for the MEG process is a heterogeneous material from which the electrodes are constructed, and allows the production of an oxalate intermediate. From the intermediate, a range of two-carbon chemicals can be formed.

Liquid Light is seeking to license its process technology to manufacturers for chemical production. ■

(*Continued from p. 14*)

lbl.gov) and Argonne National Laboratory (Ill.; www.anl.gov). The catalysts feature a hollow nanoframe structure with 3D platinum-rich surfaces that are accessible for catalytic reactions, explains LBL chemist Peidong Yang. "By greatly reducing the amount of Pt needed for O_2 reduction and H_2 evolution reactions, our new class of nanocatalysts should lead to the design of next-generation catalysts with greatly reduced cost but significantly enhanced activities," he says.

When encapsulated in an ionic liquid, the Pt/Ni nanoframes exhibited a 36-fold enhancement in mass activity and 22-fold enhancement in specific activity compared with conventional Pt nanoparticles dispersed on carbon for the O_2 reduction reaction. An order-of-magnitude enhancement for the H_2 evolution reaction was achieved when electrochemically modifying the Pt/Ni nanoframes with $Ni(OH)_2$, says LBL. ❑

CO_2 GETS GROUNDED

As major carbon capture and storage projects enter the startup phase, R&D efforts to reduce the costs for capturing CO_2 continue

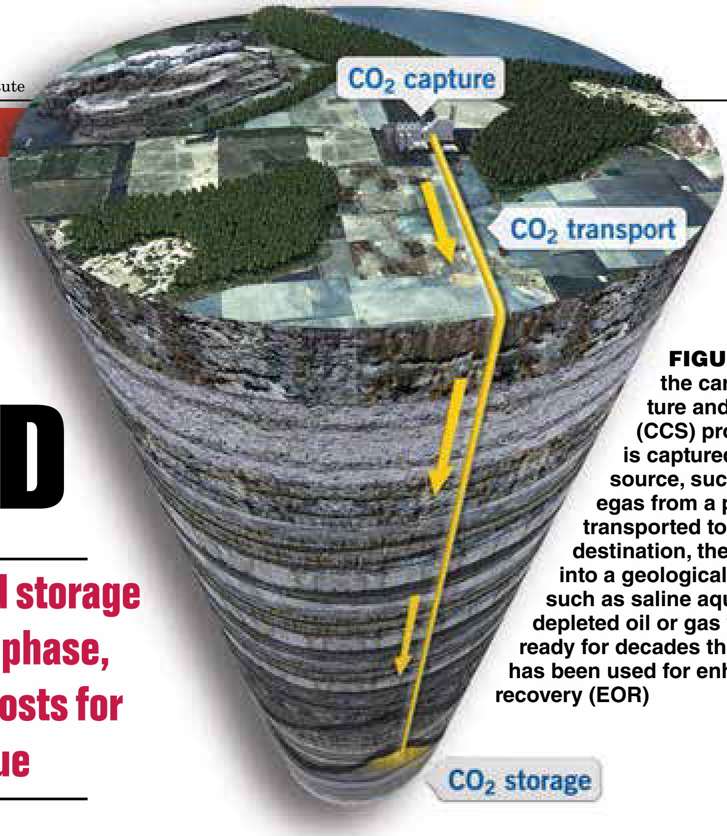

FIGURE 1. In the carbon capture and storage (CCS) process, CO_2 is captured from the source, such as the fluegas from a power plant, transported to its final destination, then injected into a geological formation, such as saline aquifers or, depleted oil or gas wells. Already for decades this process has been used for enhanced oil recovery (EOR)

"*As long as fossil fuels and carbon-intensive industries play dominant roles in our economies, carbon capture and storage (CCS) will remain a critical greenhouse gas reduction solution. With coal and other fossil fuels remaining dominant in the fuel mix, there is no climate friendly scenario in the long run without CCS.*" So begins the 2013 edition of the "Technology Roadmap — Carbon Capture and Storage," published last year by the International Energy Agency (IEA; Paris, France; www.iea.org). "This decade is critical for moving deployment of CCS beyond the demonstration phase in accordance with the 2DS,*" says the report.

Although some might argue that CCS deployment is moving too slowly, progress is being made. As of February 2014, there are 12 large-scale projects in operation globally, 9 under construction and another 39 in various stages of development planning, according to the Global CCS Institute (GCCSI; Melbourne, Australia; www.globalccsinstitute.com), which published "The Global Status of CCS: February 2014" on the 18th of February. The 21 projects in operation or under construction represent a 50% increase since 2011 — a sign of growing confidence in the application of CCS technology at large scale, says the report. Since 2011, China has doubled its number of projects, with 12 large-scale CCS projects.

*IEA's 2°C senario (2DS) describes how technologies across all energy sectors may be transformed by 2050 for an 80% chance of limiting average global temperature increase to 2°C.

CCS background

An integrated CCS project (Figure 1) involves capturing CO_2 from a large stationary source, transporting the captured CO_2 and injecting it under pressure deep into the earth to a geological formation where it will, hopefully, be stored or sequestered indefinitely instead of entering the atmosphere. Such geological formations include depleted oil-and-gas wells and saline aquifers. In fact, the idea is not new — CO_2 injection has been used for many years for enhanced oil recovery (EOR), in which case, the goal has been to get more oil per well rather than for environmental concerns.

GCCSI maintains a comprehensive database of all large-scale CCS projects around the world — currently a total of 60 projects. Of those 60 projects, 10 involve post-combustion capture technology, all of which involve power plants (Table 1). Other methods used for capturing the CO_2 are pre-combustion from natural gas (13 projects) or gasification (22 projects); oxy-fuel combustion (4 projects); separation from industrial processes (9 projects), such as ammonia production; or not yet determined (2 projects).

A more extensive database, which also includes smaller-scale and pilot CCS projects, is maintained by Howard Herzog, senior research engineer at the Massachusetts Institute of Technology (MIT; Cambridge, Mass.; https://sequestration.mit.edu/tools/projects/index.html).

Carbon capture mature, but ...

Capturing carbon dioxide from gas streams has been used for over 70 years, such as for "sweetening" natural gas, to purify synthesis gas or hydrogen from gasifiers and reformers. As such, CO_2 capture can be considered a mature technology. However, when one considers the major sources of anthropogenic CO_2 entering the atmosphere — namely combustion processes in power plants, cement kilns or steel mills — the conditions are such that the process is very expensive. Unlike natural gas sweetening, in which gas streams are typically under high pressure and contain little or no oxygen, fluegas from a combustion plant is closer to ambient pressure, so the operating conditions for the CO_2 scrubber are very different. And the presence of O_2 leads to degradation of traditional CO_2 absorbers, such as monoethylamine (MEA), as well as to corrosion problems. As a result, the application of

TABLE 1. LARGE-SCALE,* INTEGRATED CCS PROJECTS USING POST-COMBUSTION CO_2 CAPTURE FROM POWER PLANTS						
Name of project	**Region**	**Stage/status**	**Transport**	**Storage**	**Capacity, m.t./yr**	**Startup date**
Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project	Canada	Execute/ active	Onshore-to-onshore pipeline 51–100 km	EOR	1 million	n.s.
Bow City Power Project	Canada	Evaluate/ planned	Onshore-to-onshore pipeline 51–100 km	EOR	1 million	2017
Emirates Aluminum CCS Project	Middle East	Evaluate/ planned	Onshore-to-onshore pipeline 351–400 km	EOR	2 million	2018
Industrikraft Möre AS Norway	Europe	Identify/ planned	Onshore-to-onshore pipeline	n.s.**	1.4 million	2016
Korea-CCS 1	Korea	Evaluate/ planned	Shipping/tanker	GEO (Offshore deep saline formations)	1.5 million	n.s.
NRG Energy Parish CCS Project	Texas	Define/ planned	Onshore-to-onshore pipeline 101–150 km	EOR	1.4 million	2016
Peterhead Gas CCS Project	Europe	Define/ planned	Onshore-to-offshore pipeline 101–150 km	GEO (depleted oil/ gas reservoir)	1 million	n.s.
Rotterdam Opslag en Afvang Demonstratieproject (ROAD)	Europe	Define/ planned	Onshore-to-offshore pipeline <50 km	GEO (depleted oil/ gas reservoir)	1.1 million	2017
Sinopec Shengli Oil Field EOR Project (Phase 2)	China	Define/ planned	Onshore-to-onshore pipeline 51–100 km	EOR	21–30 million	2015/2016
Surat Basin CCS Project (formerly Wandoan)	Australia and New Zealand	Evaluate/ planned	Onshore-to-onshore pipeline 151–200 km	GEO (Onshore deep saline formations)	2.5 million	2017/2018

Notes:
* Large-scale integrated CCS projects are defined as those that involve the capture, transport and storage of CO_2 at a scale of at least 800,000 m.t./yr of CO_2 for a coal-fired power plant, or at least 400,000 m.t./yr of CO_2 for other emissions-intensive industrial facilities (including natural-gas-fired power generation).

** n.s = Not specified
EOR = Enhanced oil recovery
GEO = Dedicated geological storage
Source: the Global CCS Institute

post-combustion CO_2 capture from huge stationary sources has — for the most part** — eluded commercial status, while considerable R&D has been, and continues to be aimed at developing new absorbents and other means to reduce the costs for capturing CO_2 from fluegas.

Full scale ahead

Shell Cansolv (Montreal, Canada; www.shell.com/shellcansolv) has developed a process to treat post-combustion (fluegas) streams, which are at atmospheric pressure and contain high levels of O_2, and where the CO_2 is quite dilute. The presence of O_2 introduces potential corrosion and solvent degradation concerns to manage, and the lower pressure means that equipment sizes are much larger, says the company.

The Cansolv process (Figure 2) uses a regenerable solvent — a proprietary amine technology — to capture the CO_2 from the fluegas and release it as a pure stream, which can be sold for enhanced oil recovery (EOR), as a commodity chemical or for eventual sequestration.

SaskPower (the first entry in Table 1) will be Cansolv's first (and the world's first) commercial application of post-combustion CO_2 capture at a power station. Provincial regulations limiting the emissions of CO_2 from power stations to 420 kg/MWh forced SaskPower (crown-owned power provider in Saskatchewan) to evaluate the economics of replacing an aging 150-MW turbine (Boundary Dam unit 3) with an equivalent combined-cycle gas turbine (CCGT), or to retrofit the station by equipping it with CCS. After a thorough evaluation, Saskpower came to the conclusion that post-combustion CO_2 capture using the Cansolv process with CO_2 sold into nearby EOR operations was the better net present value (NPV) solution. The construction of the plant was completed in 2013.

A significant advantage of Shell Cansolv's technology is cost and minimal environmental impact. The technology uses regenerable amines to capture both SO_2 and CO_2, which means that no direct waste byproducts are generated. In addition, 1 million metric tons (m.t.) per year of CO_2 will be captured from the coal-fired unit. This will be compressed, transported through pipelines and used for EOR in nearby oilfields. This project is a milestone for the fossil-fuel power industry worldwide, as it proves the viability of large-scale CO_2 capture and demonstrates that carbon capture can be brought to commercial scale, says the company.

Cansolv has applied its patented SO_2-capture systems at coal-fired power plants in China that are currently in operation. The technology employed there is essentially identical, using a different amine that targets SO_2 instead of CO_2.

** Since 1976, Searles Valley Minerals captures around 270,000 m.t./yr of CO_2 (from a coal-fired power plant) at its soda ash plant in Trona, Calif. The CO_2 is captured using an amine solution, and used for the carbonation of brine in the production of soda ash.

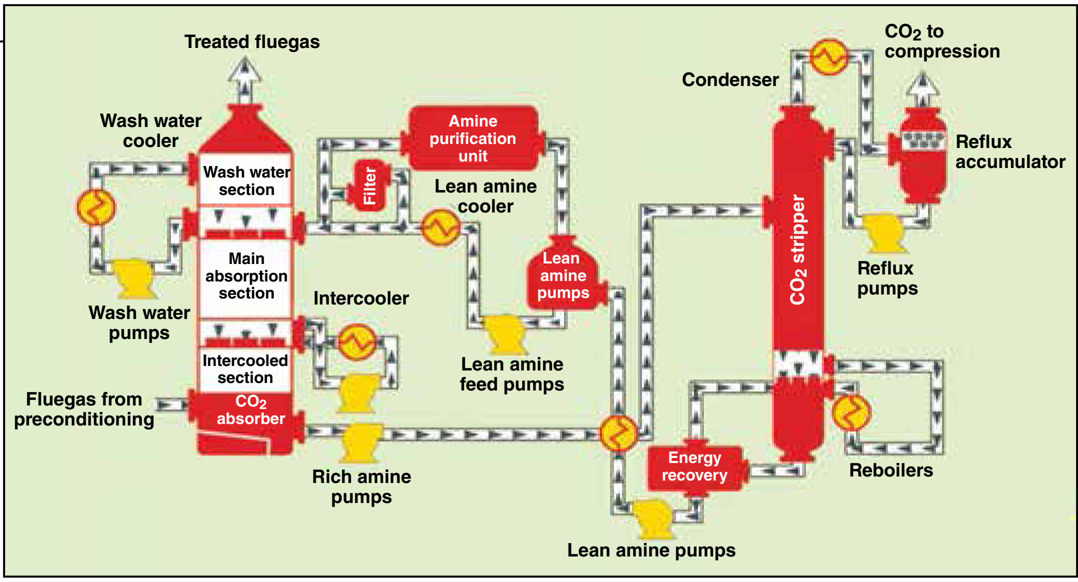

FIGURE 2. The Cansolv CO_2-capture system uses an advanced amine solution to absorb CO_2 from fluegas. The captured CO_2 is then stripped from the amine, and the recovered CO_2 can be compressed for injection into a geological formation

Last September, Shell Cansolv and Technip (Paris, France; www.technip.com) signed an agreement to leverage their respective expertise in marketing an end-to-end solution for CCS projects. Last month, Technip was awarded a contract to provide front-end engineering design (FEED) for the onshore elements of the Peterhead Gas CCS demonstration in Aberdeenshire, Scotland — a project to capture, compress and transport by pipeline 1 million m.t./yr of CO_2 to an offshore gas reservoir for longterm storage beneath the North Sea. The design will utilize Shell Cansolv's CO_2 capture technology.

Meanwhile, Mitsubishi Heavy Industries, Ltd. (MHI; Tokyo, Japan; www.mhi.co.jp) announced in January that a demonstration test for capturing and sequestering CO_2 recovered from emissions from a coal-fired power plant — conducted jointly by MHI and Southern Company Services, Inc. (SCS; Atlanta, Ga.; www.southerncompany.com), has completed an initial demonstration phase.

The demonstration test got underway in June 2011. After verifying the technology for recovering CO_2 from the coal-fired plant fluegas, as well as recovery performance, integrated capture and sequestration demonstration testing began in August 2012. High-performance continuous and stable operation of the large-scale CO_2 recovery plant was confirmed.

The CO_2-capture demonstration plant that supplied the CO_2 under this project was built jointly by MHI and SCS, and is currently the world's largest in scale (operating), handling some 500 m.t./d. It has capacity to recover 150,000 m.t./yr of CO_2 with recovery efficiency above 90%. For CO_2 recovery, the facility adopts the KM CDR Process, which uses a proprietary KS-1 high-performance solvent for CO_2 absorption and desorption that was jointly developed by MHI and the Kansai Electric Power Co., Inc. (*Chem. Eng.* January 2008, p. 12).

Progress on the amine front

Last August, BASF SE (Ludwigshafen, Germany; www.basf.com) granted a license to JGC Corp. (Yokohama, Japan; www.jgc.co.jp) for a gas-treatment technology, called OASE, that JGC will use in the plant for Japan's first large-scale CCS demonstration project in Tomakomai, Hokkaido, Japan. Performance testing of the plant is scheduled for completion by the beginning of 2016.

With technology from BASF, CO_2 will be removed from a gas stream from a petroleum refinery close to the location. The unit is designed to capture about 200,000 ton/yr of CO_2, preventing it from being released into the atmosphere.

Since 2009, BASF and Linde AG (Munich, Germany; www.linde.com) have been developing and testing new technology for capturing CO_2 from fluegas in a 7.2-ton/d pilot plant at RWE's Niederaussem power plant near Cologne, Germany. New aqueous-amine-based solvents developed by BASF can reduce energy input by about 20%, says the company. The partners intend to operate the pilot plant until the end of 2016.

Since 2010, BASF has also been working with RTI International (Research Triangle Park, N.C.; www.rti.org) to further develop cost-effective technology to capture CO_2 from coal-fired power plants. The collaboration is investigating non-aqueous solvent systems that can be recycled. The capture process could use 40% less energy than conventional amine-based processes, says BASF.

Meanwhile, last June, the Energy Sector of Siemens AG (Erlangen, Germany; www.siemens.com) completed a concept study and successful testing of its PostCap process using fluegas from a natural-gas-fired combustion process, achieving 3,000 hours of operation. Prior to this, the PostCap pilot facility operated for more than 6,000 h on fluegas from E.ON's coal-fired Staudinger Power station near Frankfurt am Main, Germany. Drawing on experience gained from pilot operations, the company offers PostCap technology for large-scale projects, says Siemens.

In the PostCap process, an amino acid salt is used as an absorbent instead of conventional amine. Because amino acid salts do not evaporate, no additional washing unit and related equipment on top of the absorber is required. Furthermore, the solvent is said to be robust against O_2 degradation. Through improved process configuration, the thermal energy demand for stripping CO_2 from the solvent is lower than that required by conventional MEA, which leads to a reduction by about 20% with PostCap, says the company. ■

Gerald Ondrey

MASTERING THE CHALLENGES OF AIR-SENSITIVE MATERIALS

New equipment strives to make handling air-sensitive materials more efficient and economical

While air-sensitive materials may not be a part of every chemical process, certain catalysts, OLED (organic light-emitting diode) applications, inert gas welding, lithium-ion battery applications and other chemical processes do, indeed, require the inclusion of air-sensitive materials. And, when such materials are present at either research or mass-production scale, it can create an abundance of challenges for those charged with handling them.

Depending on the material and the application, there are generally two possible reasons why processing air-sensitive materials may be an issue. The first is that if the material comes in contact with the air, it could be destroyed or oxidized and lose its properties, rendering it useless in the process or damaging the final product. The second possible reason is that some air-sensitive materials may react strongly with air, which could be dangerous for the individual handling the material. And, in some cases, there are materials where both these reasons may come into play. In any and all of these situations, working under an inert atmosphere while handling air-sensitive materials is critical.

Not only is it critical, but also it is fraught with challenges, such as balancing the needs of the application with the cost of the equipment, managing the controlled atmosphere and finding the best equipment for specialized applications. Manufacturers of equipment developed to handle air-sensitive materials are aware of these difficulties and are working to improve existing technologies to meet the needs of the processors who must use them.

Need versus cost

In many situations involving air-sensitive materials, the cost of the equipment needed to maintain a tightly controlled atmosphere can be astronomical. However, Bob Applequist, product manager, with Labconco (Kansas City, Mo., www.labconco.com) says it is important to consider the application and the level of controlled atmosphere that it truly mandates, and select equipment based upon the actual requirements. For example, is a 1 part-per-million (ppm) oxygen atmosphere really necessary or can you successfully complete the process with an atmosphere of 5 ppm oxygen?

"As manufacturers, we try to assess the required needs of the application and then bridge the gap between the absolute needs of the equipment user and the economic limits the user is faced with," says Applequist.

As a result, many equipment providers are developing more economical products. For example, Labconco offers its line of Precise gloveboxes (Figure 1) to provide an economical solution to more sophisticated gloveboxes. They have seamless, one-piece molded polyethylene shells that withstand chemicals, are easy to clean and offer a simple design, which allows them to be customized with optional accessories to meet application needs. Precise Controlled Atmosphere gloveboxes are designed to create low-oxygen or low-moisture environments. And, Precise HEPA- (high-efficiency particulate absorption) Filtered gloveboxes and Xpert Weigh Boxes have inlet and outlet HEPA filters to protect the operator from hazardous airborne particles and powders.

In many pharmaceutical and chemical applications such as hydrogenation, carbon filtration, catalyst recovery, pre-filter for microfiltration, active pharmaceutical

Labconco

FIGURE 1. Precise gloveboxes can be an economical alternative to more sophisticated gloveboxes

Powder Systems

FIGURE 2. The simplefilter consists of a heated insulated vessel with a filtration medium attached to a heated base and a side discharge hatch for efficient drying and removal of the product

ingredients (APIs) and intermediate filtration, the available technologies can be costly and complex, says Camille Flores, business development manager with Powder Systems, Ltd. (Liverpool, U.K.; www.powdersystems.com). As a simplified alternative, the company developed the simplefilter with an agitation option to simplify and reduce costs in these processes.

The simplefilter consists of a heated insulated vessel with a filtration medium attached to a heated base and a side discharge hatch for efficient drying and uncomplicated removal of the product through a purged GloveBag (Figure 2). Combined filtration and drying equipment, such as the simplefilter, provides an ergonomic and efficient answer to pharmaceutical, biopharmaceutical, chemical and laboratory industry requirements, where safe heel removal is vital because the intermediate or end product is often of great value.

"The simplefilter and its GloveBag are a cost-effective alternative to the costly investment of a pressure filter plate, tray dryer or similar and stainless-steel gloveboxes for product transfer and offloading," notes Flores. "The capital investment and footprint are greatly reduced by using the simplefilter technology. And when the total recovery of the finished product is essential for chemical development due to the value of the product, every gram can be recovered safely using the simplefilter and the GloveBag with a low capital investment."

The cost of ownership often drives the use of flexible containment over rigid systems. This is seen in production installation, but cost can also become a factor because the processor is doing a trial or a preproduction run to test the feasibility of a process or product, says Alan George, business development manager with ILC Dover (Frederica, Del.; www.ilcdover.com). "If a customer is trying to verify that his or her product will work in his or her own customer's application, they often don't want to lay out capital on new or expensive equipment because the product might not make it to market, so we need to create something that is inexpensive and flexible enough to attach to their existing equipment without modifying it," he explains.

For these applications, ILC Dover has adapted the DoverPac Flexible Containment Technologies (Figure 3) to include enclosures for almost any process. Use of the company's ArmorFlex film and integral gloves and sleeves can support operations from filter dryer discharge to tray dryer loading and unloading.

The benefits of this flexible system, says George, are quick implementation from design through installation, reduced capital expenditures and improved operator ergonomics because the enclosures are connected to a frame with elastic cords, which allow the enclosure and gloves to move with the individual users. "It allows users to complete and try the process without a large capital outlay for small batch pre-production runs, while making it ergonomically easy and keeping costs low," explains George.

Managing an inert atmosphere

In an inert atmosphere, it's all about the chemistry, the reaction and the percentage of reaction efficiency, explains Labconco's Applequist. "Aside from trying to protect sensitive materials from the atmosphere, the problem is often the efficiency, or lack thereof, of the reaction. For this reason, one of the biggest challenges for our customers is the ability to properly manipulate the gas chemistry inside a controlled-atmosphere glovebox. And, a lot of operators don't realize that they are responsible for using the controls of the glovebox to bring gas in and out to create and maintain the proper environment inside the equipment for the duration of the process," continues Applequist.

Labconco launched the AtmosPure Re-Gen Gas Purifier glovebox accessory for this reason. The product produces an ultra-pure inert atmosphere for materials that are sensitive to moisture or oxygen by circulating an inert gas and removing oxygen and moisture inside the box. The purifier has the capacity to remove up to 5 L of O_2 and 660 g of moisture at standard temperature. And, Applequist says, depending on the application, glovebox liner material and frequency of use, regeneration may be necessary only once every one to three months and completed in only 13 h, which simplifies the task of managing the environment in critical applications.

Jerome Soullard, sales manager, technical marketing, with M.Braun Inertgas-Systeme GmbH (Garching, Germany; www.mbraun.com) agrees that maintaining an atmosphere can be difficult, especially over long-term applications. "Generally speaking, the biggest challenge is to keep the inert atmosphere in the glovebox over the long term when handling air-sensitive materials, or during the whole production cycle," says Soullard. And, he says, in some new applications, such as OLEDs, the challenge is to scale up to large volumes and still maintain the inert atmosphere.

ILC Dover

FIGURE 3. ILC Dover has adapted the DoverPac Flexible Containment Technologies to include enclosures for almost any process

M.Braun recently built large enclosures with complete production lines under inert atmosphere inside. (Figure 4) "The main difficulty is to be able to maintain an inert atmosphere with a specific gas purifier unit able to purify these large volumes of inert gas," says Soullard.

There are other associated challenges in these larger-scale applications, as well. For example in OLED applications, in addition to keeping the inert atmosphere, it is also necessary to keep the atmosphere clean and free of particles. Laminar gas/air flow conditions, as they are commonly used in cleanrooms, set the standard for particle-free environments. For this reason, M.Braun adopted cleanroom concepts and transferred the core technical elements into the inert gas technology, including the HPL membrane.

"Choosing optimum sub-components, and placing them under clean room conditions, can allow large-scale manufacturing with moisture and oxygen concentrations below 1 ppm," he says. "Using this interdisciplinary approach makes it possible to produce systems ranging from standard R&D equipment up to complete production lines with inert laminar flow conditions, reducing the particle load on substrates and cover glasses to a minimum, which enhances the quality of the processes considerably."

Specialized material handling

In addition to the general challenges, there are some applications that require special equipment due to the hygroscopic or explosive properties of the materials being

M.Braun

FIGURE 4. **The MBRAUN 3000-IGMS is said to be the world's largest and most powerful inert-gas purifier**

handled, says Peter Selby, powder handling project specialist with Dec USA Inc. (Brick, N.J.; www.dec-group.net).

"Hygroscopic materials that absorb moisture from the air, materials that explode when exposed to air and — especially in the pharmaceutical industry — materials that pose a health hazard for workers must be handled under completely inert conditions using the most efficient equipment available," says Selby.

"In addition, due to even more stringent health-and-safety regulations, closed/contained powder-handling solutions have become an issue even for industries that have not been concerned until recently. For example, the concern is growing to an extent that in the electronics and heavy-metals industries, they may completely change their manufacturing procedures," says Selby.

For example, in electronics, explains Selby, the concern is protecting the materials and process from any foreign contaminants. The same can be said for metals, such as cadmium and lithium, used in the manufacture of batteries. "Not only must these processes be protected from foreign contaminants, but in many cases, these materials can be very harmful to people."

Dec's containment solutions, at the powder source, such as with the company's Drum Containment System (DCS), and at the delivery point, such as with the Powder Transfer System (PTS), satisfy both protection of the processes and safety of the operator.

The DCS is a stainless-steel cylindrical glovebox with glass cover and two glove ports. Economical in comparison with conventional isolation systems, the DCS ensures precise, contamination-free evacuation of drums and ensures safe handling of toxic or explosive powders. (Figure 5). It also works in combination with the PTS.

Dec USA

FIGURE 5. **The DCS is a stainless-steel cylindrical glovebox with glass cover and two glove ports**

The PTS is a reliable method of transferring and dispensing both dry and wet powders and granules. Its unique filtration concept with a flat membrane makes it the only vacuum dense-phase system on the market, according to Selby.

The PTS uses both vacuum and pressure to move powders as if they were liquid, dispensing with the need for gravity charging, making multi-floor processes unnecessary. The dense-phase system provides total containment where necessary and removes oxygen from powder before entering it into the process. It is an easy-to-clean, clean-in-place system that is both GMP (good manufacturing practice) and ATEX compliant.

While the use of air-sensitive materials certainly doesn't simplify the process, newer, more economical and efficient handling systems are making it easier to master the challenges these tricky materials present. ■

Joy LePree

FOCUS ON

Temperature Measurement And Control

Invensys Foxboro


Huber Kältemaschinenbau

Turck

A dual-sensor temperature transmitter with HART protocols
The RTT80 temperature transmitter (photo) offers signal reliability, longterm stability, high precision and advanced diagnostics. The RTT80 is a mid-tier, two-wire temperature transmitter available with HART (and soon to be released Foundation Fieldbus) protocols, dual-sensor inputs, universal housing, diagnostics, alarms, resistance temperature detectors (RTDs) and thermocouples. Some of the key features are the following: intelligent hot-sensor backup switches to a secondary sensor in the event of a burnout; corrosion measurement for better predictability about the sensor's quality and life expectancy; corrosion detection to prevent export of incorrect values; drift detection; and automatic temperature-range sensor change to switch the primary temperature measurement from sensor 1 to sensor 2 (a different sensor type). — *Invensys Foxboro, Foxboro, Mass.*
www.fielddevices.foxboro.com

Temperature control hoses with improved flow characteristics
These hoses (photo) feature smooth internal walls that improve the flow characteristics and heat transfer. Compared to traditional hoses with fluted internal walls, these hoses accelerate heating and cooling processes. According to the manufacturer, tests with different reactor systems have shown a reduction of the heating and cooling times by up to 30%, depending on the application. The insulated hoses can be used with operating temperatures of –60 to 260°C. They are available in lengths of 100, 150, 200 and 300 cm. The hoses can be coupled directly to reactor systems and other units by use of connecting threads on both ends. — *Huber Kältemaschinenbau GmbH, Offenburg, Germany*
www.huber-online.com

A thermal controller with user-friendly software
The Model 5R7-350/347 is an economical thermal controller that is designed to operate with thermoelectric (Peltier effect) modules. Most of these modules can be operated in either a cooling or a heating mode, depending on current directions. The 5R7-350/347 can be field-configured for either of these operating modes. These temperature controllers were designed with a proportional-integral control algorithm, and a fixed or adjustable proportional bandwidth and integral rate permit optimizing individual systems. — *Oven Industries, Mechanicsburg, Pa.*
www.ovenindustries.com

Fully programmable temperature sensor offers all-in-one solution
The TS530 temperature sensor (photo) features an integrated RTD and combines the display, process connection and RTD all in a single part. Simple push-button programming and large LED displays contribute to easy operation. The display can turn up to 340 deg for flexible viewing in the field, while the sensor also sends feedback to a PLC for remote monitoring. — *Turck, Plymouth, Minn.*
www.turck.us

A temperature scanner for both the laboratory and the factory
The 1586A Super-DAQ Precision Temperature Scanner offers up to 40 analog input channels and scan rates as fast as 10 channels per second. The unit can measure thermocouples, platinum resistance thermometers (PRTs), thermistors and more. With the flexibility of both internal and external input modules, the 1586A has a color display with channel indicators that can chart up to four channels simultaneously. It features four modes of operation (scan, monitor, measure and digital

Note: For more information, circle the 3-digit number on p. 76, or use the website designation.

Ashcrof

WIKA Alexander Wiegand

multimeter), and alarms that indicate when a channel measurement exceeds an assigned high or low limit. — *Fluke Corp., Everett, Wash.*
www.flukecal.com

These bimetal thermometers eliminate mercury

Bimetal thermometers (photo) available from this company eliminate the use of mercury to measure temperature. They are available in dial diameters from 2–5 in. and for temperature ranges from –80 to 1,000°F, and in standard stem lengths from 2.5–24 in. Special order stem lengths of up to 60 in. are available. Maxivision thermometers provide a fixed rear or bottom stem, while the Everyangle design allows the stem angle to be adjusted. The stainless-steel thermometers are hermetically sealed for easy wash-down, or liquid-filled to counter high vibration. — *Ashcroft Inc., Stratford, Conn.*
www.ashcroft.com

Miniature temperature sensors designed for tight spaces

These new temperature sensors (photo) fit into even the tightest of spaces. The model TF40 was developed specifically for use in ventilation ducts, and model TF41 was developed for outside-temperature measurement. The measuring elements of both sensors are inserted into a UV-resistant plastic housing that measures 44 × 32 × 30 mm. The instruments are compatible with all common control systems. The model TF40 is tailored to the needs of air-conditioning and ventilation technology and offers an optional plastic mounting flange and thermowell. The TF41 is primarily suited to applications in renewable energies, HVAC and refrigeration technology. An additional clip-on protective module prevents erroneous measurements caused by too-strong sunlight in outside applications. — *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.com ■

Dorothy Lozowski

Circle 28 on p. 76 or go to adlinks.che.com/50975-28

Fluid Components International

APRIL New Products

Benko Products

Kaeser Kompressoren

MKS Instruments

Presto Lifts

These manometers feature extended service intervals

The *a*-Baratron Capacitance Manometer (photo) has a high tolerance to ambient temperature changes. Internally heated to 45, 80 or 100°C, this manometer offers full-scale measurement ranges from 0.1 to 1,000 Torr, and service intervals that are up to four times longer than previous models, says the company. Its all-digital architecture and new sensor-heating system contribute to longterm reliability. Corrosion-resistant, due to its nickel-alloy construction, these manometers can be flexibly configured for many existing or new processing systems. — *MKS Instruments, Andover, Mass.*
www.mksinst.com

These compressors have new energy-saving features

The SFC 30 (photo) and SFC 30S compressors are variable-drive rotary screw compressors with updated specific-power features, including a direct-drive design, premium efficiency motors, lower internal pressure differentials and optimized screw elements. Built-in heat-recovery options provide further energy savings. Other new features on these compressors include enhanced cooling systems, integral moisture separators (with drain), and electronic thermal management. The SFC 30S has a flow range of 37–171 ft^3/min at 125 psig and is available with pressures up to 190 psig. The SFC 30 has a flow range of 47–202 ft^3/min at 125 psig, with pressures up to 217 psig. — *Kaeser Kompressoren SE, Coburg, Germany*
www.kaeser.com

Use this flowmeter to optimize air-gas ratio in burners

The ST75 Air/Gas Flowmeter (photo) measures fuel gas, process gas, inert gas, waste gases and air in a variety of small line sizes. Designed to optimize air-gas ratio for control of burners in boilers, ovens and heaters, this flowmeter provides three outputs; the mass flowrate, the totalized flow and the media temperature, allowing users to monitor and control fuel and air requirements. The ST74 is designed for small line sizes (0.25–2 in. diameter), making it useful in a wide variety of industries, including chemical processing, electric power, food and beverage, pharmaceuticals and semiconductors. Offering direct-flow measurement with thermal dispersion technology, the ST75 eliminates the need for additional pressure and temperature sensors or flow computers. There are also no orifices or inlets to clog or foul, significantly reducing scheduled maintenance and unplanned shutdowns. — *Fluid Components International LLC, San Marcos, Calif.*
www.fluidcomponents.com

These stackers are designed with ergonomics in mind

The PowerStak line of compact fully powered stackers (photo) have been

Note: For more information, circle the 3-digit number on p. 76, or use the website designation.

Spectronics

updated with new ergonomic features. The units are built on a short, stable wheelbase to enhance maneuverability, even in tight quarters. An ergonomically designed handle puts all controls within operator reach for comfort and convenience. Forward- and reverse-drive thumb switches are located on both sides of the handle to accommodate either left- or right-hand operation. The unit's narrow mast and offset control handle ensure a clear forward view, with virtually no blind spots. An automatic brake halts travel when the drive/steering handle is released. Other features include a reduced-speed capability for more precise positioning and new component arrangement for better heat dissipation. The equipment's maximum load capacity is 2,200 lb, with a maximum lift height ranging from 62 to 150 in. — *Presto Lifts Inc., Norton, Mass.*
www.prestolifts.com

A bright, violet LED provides contrast and precision for leaks

The OLK-441 Leak Detection Kit (photo) is designed for use with hydraulic systems, compressors, engines, gearboxes and fuel systems. The kit includes the Opti-Lux 400, a flashlight that features a high-output violet light-emitting diode (LED), allowing for precise detection of fluid leaks through the illumination of fluorescent dyes. The violet light provides more contrast than standard blue inspection lamps, allowing for easier detection, says the company. The inspection range for the flashlight is up to 25 ft. The kit's other components include a bottle of patented concentrated fluorescent dye, a spray bottle of dye cleaner, a charger, dye-treatment tags and fluorescence-enhancing glasses. These components come packed in a compact carrying case. — *Spectronics Corp., Westbury, N.Y.*
www.spectroline.com

Melt materials in drums or totes with this versatile oven

The Sahara Hot Room Model S32 oven (photo, p. 30) can quickly melt materials in drums or totes. Capable of heating 32 drums on pallets (or eight totes), the Sahara Hot Room S32 can use saturated steam (up to 200 psig), hot oil or hot water as the heating medium. Fully insulated, this steel-constructed

New Products

Stafford Manufacturing

Bronkhorst High-Tech

oven is forklift-portable and includes built-in spill containment. The heating capability of each oven is designed based on users' needs, with optional features available, such as air circulation, exhaust system capabilities and digital temperature control. — *Benko Products, Sheffield Village, Ohio*
www.benkoproducts.com

Otek

A mass flow controller with no moving parts or bypass
The T23 mass flow controller (photo) contains no moving parts and has no obstructions to the flow path, making them capable of performing in applications where there is very low pressure drop. With minimal sensitivity to moisture and particulate matter, the T23 works on the basis of direct through-flow measurement with no bypass. The meter's electronic housing is water- and dust-proof. The T23's updated design features an integrated direct operating valve that can handle a wide range of high gas flowrates. — *Bronkhorst High-Tech BV, Ruurlo, the Netherlands*
www.bronkhorst.com

Vacuum conveyors with updated interactive transfer systems
The VS Series Multijector vacuum conveyor (photo) can transfer materials at a wide range of flowrates — from as little as 10 lb/h to as much as 12,000 lb/h over distances up to 200 ft, when used with a level-controlled buffer hopper. Used for the transfer of powders, granules, pellets, capsules, tablet or food particles under vacuum conditions, these conveyors can supply many types of process equipment on demand. An interactive, enclosed transfer system gives these conveyors important advantages in the transfer of difficult or sensitive materials. The cyclic vacuum plug-flow conveying arrangement prevents product separation or segregation. — *Volkmann Inc., Bristol, Pa.*
www.volkmannusa.com

Continue signal transmission, even after loop-power failure
The LPD series of loop-powered bargraphs (photo), available in vertical or horizontal configurations, can be installed in parallel as a replacement for analog loop meters. In the event of loop failure, the meter will flash its display for approximately 20 seconds and then transmit an isolated Serial I/O for data recording and recovery. Only 2 in. deep, the meter can be installed into industry-standard panels. The meters come with a plastic or metal (aluminum-nickel plated) case to ensure performance in harsh environments. In addition, LPD meters are also available in nuclear grades. — *Otek Corp., Tucson, Ariz.*
www.otekcorp.com

Couple many components, even those with dissimilar shafts
This company's line of rigid couplings (photo) are offered in one-, two- and three-piece designs, with a variety of configurations and sizes for connecting virtually any type of pump, mixer or drive shaft. All designs can incorporate straight- or stepped-bores for mating dissimilar shafts. Machined from high-temperature alloys, stainless steel or aluminum, these couplings are available in diameters from 1 to 6 in., with or without keyways, which can be formed to customer specifications. — *Stafford Manufacturing Corp., Wilmington, Mass.*
www.staffordmfg.com ■

Volkmann

Mary Page Bailey

IFAT

resources. innovations. solutions.

Flexim Flexible Industriemesstechnik

Microdyn-Nadir Group

Pump Solutions Group

The world's largest environmental technology trade show, IFAT (www.ifat.de), takes place in Munich May 5–9. A record of nearly 3,000 companies from 50 countries are presenting innovations and services in water, sewage, waste and raw materials management, covering some 230,000 m^2 of exhibition space. What follows is a small sample of new products being exhibited at the show.

This modular analyzer measures water parameters

As the population continues to grow, the need for clean drinking water is rising. Today, water-treatment plants utilize a wide variety of different analysis tools to measure various water parameters. This company has made its mission to simplify industrial water treatment, and is introducing its new online analysis system, the Type 8905 (photo), which is said to combine, for the first time, the largest number of measurement functions in potable-water treatment into a single, modular device. Hall A5, Stand 423 — *Bürkert Werke GmbH & Co. KG, Ingelfingen, Germany*
www.buerkert.de

Bürkert Werke

The launch of a new membrane for MBRs

Membrane bioreactors (MBRs) are a well-established and indispensable technology in wastewater treatment. This company offers its Bio-Cel membrane (photo) module with an integrated mechanical cleaning process (MCP). The patented MCP helps reduce operating costs by reducing the formation of a fouling layer by supporting the crossflow aeration through the use of inert, organic material. The MCP granulate is added directly into the activated sludge. The airflow induced by the module-integrated membrane aeration system draws the MCP granulate up between the membrane sheets. As the MCP granulate rises, the membrane area is continuously cleaned through the direct contact of the granulate with the sludge on the membrane surface. The Bio-Cel MCP system enables much higher specific flowrates. This lowers investment costs (smaller membrane area needed) and reduces energy consumption (crossflow) for the entire system by 30–50%. At IFAT, the company will be introducing the next generation of Bio-Cel. Hall A2, Stand 516 — *Microdyn-Nadir Group, Wiesbaden, Germany*
www.microdyn-nadir.de

Positive displacement pumps for all your needs

On display at the stand of this major manufacturer of positive-displacement pumps is the Almatec E-Series (photo) of air-operated double diaphragm (AODD) pumps, which feature a plastic, solid-body design for use in general chemical transfer, and the AH-Series AODD pumps in high-pressure configurations for charging filter presses with chemical wastes and sludge. Also exhibited is the Neptune 700 Series Mechanical, 500/600 Series Hydraulic and PZ Series Electronic diaphragm metering pumps, which are suitable for chemical-feed and chemical injection applications. The Wilden Original (clamped) and Advanced (bolted) Series AODD pumps with innovative Pro-Flo Shift air distribution systems will be presented at the exhibition. Hall A6, Stand 214 — *Pump Solutions Group, Oakbrook Terrace, Ill.*
www.psgdover.com

Clamp-on flowmeters localize leaks in water pipelines

The Fluxus ADM 7407 ultrasonic clamp-on flowmeter is said to be a superior solution for monitoring wa-

Note: For more information, circle the 3-digit number on p. 76, or use the website designation.

Lenzing Technik

Oschatz

Festo

ter-distribution pipelines for leaks. Because the sensors are mounted on the outside pipe wall, the installation of the system does not interrupt the supply. Moreover, the permanent coupling on the pipe, the rugged stainless-steel mounting fixture (Varioflex; photo, p. 33) and the IP-68-protected sensors themselves ensures safe and longterm stable measurements — even when buried underground. A matched sensor pair combined with powerful measurement algorithms for accurate and reliable signal processing enables the Fluxus to detect even small volume streams with high precision, says the company. A network with multiple measurement points enables leaks in pipelines to be directly localized. Hall B3, Stand 141C — *Flexim Flexible Industriemesstechnik GmbH, Berlin, Germany*
www.flexim.de

This anaerobic reactor has a mixer and a membrane built in

Unlike conventional anaerobic technologies, the IM-MS (integrated mixer and membrane separator) incorporates a mixer that achieves high circulation velocities. This eliminates the need for external sludge recirculation with a drastic reduction in energy demand, says the manufacturer. Gases, solids and liquids are separated by means of a membrane, which is also integrated into the reactor. The first industrial implementation of this technology has been realized (photo), with a unit capable of treating up to 5,000 m^3/d of highly concentrated wastewater. The IM-MS technology also ensures a sustainable operation related to the reduction of very high sulfur loads. Hall 3, Stand 520 — *Lenzing Technik GmbH, Lenzing, Austria*
www.lenzing.com/engineering

Tailored and turnkey plants to utilize waste

Because the chemical composition of solid residue is heterogeneous with frequent fluctuations, the grate-incineration process has proven itself over many years. This company offers individually designed grate-firing systems for almost all solid fuels, such as rejects, discards, waste with a high calorific value, alternative fuels and secondary fuels. Individually designed boiler systems utilize the energy from the fluegas to generate usable steam. On request, it is also possible to convert the energy from the incineration process to electric power, in waste-to-energy plants (photo). Depending on requirements, both horizontal-pass and vertical-pass boilers can be used. At IFAT, this company is also presenting its know-how regarding turnkey power plants. Hall B3, Stand 271 — *Oschatz GmbH, Essen, Germany*
www.oschatz.com

This controller provides precise positions for actuators

The position controller CMSX (photo) for double-acting, quarter-turn actuators provides a pre-definable safety position for the process valve. The end positions can be defined flexibly via freely configurable analog signals. In the standard variant of the position controller, its microcontroller continuously displays these feedback signals. In closed-loop mode, the CMSX continuously compares the setpoint signal with the actual position of the quarter turn actuator. Any deviations automatically trigger an error message and an emergency stop. If there should be a power supply failure, the process valve can be brought to a previously specified safety position. Hall A1, Stand 335 — *Festo AG & Co. KG, Esslingen, Germany*
www.festo.com

Innovative oil recovery from plastic waste

As a manufacturer of specialized reactor solutions, this company has significantly advanced the development of pyrolysis processes for recovering oil from plastic waste. Two pilot projects are currently being implemented at industrial sites. In one, a European company is using a pyrolysis process for processing plastic fluff coming from car recycling. This waste can now be processed in a two-step, batch process under normal pressure to obtain recyclable oil: in the first reaction step the bulk density of the fluff is thermally compacted by a factor of 5 to 10; in the second reaction step installed downstream, a catalytic pyrolysis is performed to obtain recovery of oil. The heating of this reactor is carried out at an input temperature of 500°C by using a salt melt. Another company is recovering oil from recycled plastic using catalytic pyrolysis. For this purpose, a reactor by the exhibiting company is used, in which electric heating (2 MW) heats the machine walls up to 700°C. The product temperature is approximately 500°C in this application. Hall A4, Stand 519 — *Gebr. Lödige Maschinenbau GmbH, Paderborn, Germany*
www.loedige.de ■

Gerald Ondrey

INTERNATIONAL

POWDER & BULK SOLIDS

CONFERENCE & EXHIBITION

Netzsch Premier Technologies

The International Powder & Bulk Solids Conference and Exhibition is taking place May 6–8 at the Donald E. Stephens Convention Center in Rosemont, Ill. Featuring a large expo hall and a variety of technical sessions, as well as some hands-on demonstrations at the show's Tech Theater, this year's event expects to attract thousands of industry professionals. The conference program consists of four distinct tracks that will lead attendees through technical workshops, educational presentations and guided tours of the show floor. Each morning of the three-day conference will commence with a Keynote Technology Panel, where experts from industry and academia will discuss relevant topics, including the mitigation of combustible-dust hazards, discrete-element modeling and solids-handling applications for computational fluid dynamics. The tradeshow floor boasts over 350 registered exhibitors, who will showcase new products and services related to the solids processing industries. The following is a small selection of some of these exhibitors' offerings at this biennial event.


Porvair Filtration Group

This system uses superheated steam for extremely fine milling

The s-Jet 25 (photo) is a combination mill system consisting of a spiral jet mill and an integrated dynamic air classifier. Using superheated steam as its milling gas, this very compact unit (with a height of only 2,450 mm) can manufacture nanoparticles on a laboratory scale. High fineness can be obtained with this mill, independent of the load in the air jets. The integrated dynamic air classifier in the housing can be precisely adjusted to the desired fineness, for exact grinding parameters and reproducible product quality. The s-Jet 25 also includes integrated components on its skid for dosing, product separation, controls, fittings and steam generation. All product-contacted parts, as well as the assembly frame, are made of stainless steel. The unit is delivered completely mounted and ready for operation. Designed for use with a variety of solids, the unit is also capable of handling moist products, via a simultaneous grinding and drying process using superheated steam. Booth 2349 — *Netzsch Premier Technologies LLC, Exton, Pa.*
www.netzsch-grinding.com

Sanitary drying and agitation with these microwave units

Sanitary microwave mixers from this company feature a 75- or 100-kW microwave transmitter for uniform heating and drying of powders, slurries, greases and more. Constructed of stainless steel, the mixer unit is designed specifically for safety, with measures to prevent microwave leakage from the vessel. Featuring short batch times, a small footprint and simplified maintenance, these mixers are highly scalable for use in a variety of applications, including biomass treatment, powder dewatering, carbon-black addition, pyrolysis for plastics recycling, as well as providing gentle agitation for a wide range of processes. Booth 3826 — *Marion Mixers Inc., Marion, Iowa*
www.marionmixers.com

Control bin level, even in areas with high levels of vibration

Model CT tilt-level controls are designed for level detection of dry bulk materials in hoppers, silos, stackers, crushers and conveyors, both in general-purpose outdoor applications and hazardous-location applications. Featuring a stainless-steel probe enclosed in a rugged cast-aluminum housing, the product line includes models that are available with various degrees of weather-, dust- and explosion-proofing for flexibility in a variety of industries. These level controls can be used in operations with high levels of bin vibration and where bin walls are not available for mounting controls. Booth 2734 — *Conveyor Components Co., Croswell, Mich.*
www.conveyorcomponents.com

Fluidizing media that withstand very aggressive environments

This company's range of fluidizing media (photo), available in both sintered porous plastic and sintered porous metal, can be engineered into a variety of structures, including flat beds, cones and domes, to provide solutions for a variety of fluidizing needs. The uniform pore-size distribution of these sintered materials enables controlled and consistent distribution, ensuring even flow and efficient low-energy powder fluidization. The easily cleanable and reusable products, which are suitable even in high-temperature, chemically aggressive environments, are used in a range of markets, such as construction, food-and-beverage and pharmaceuticals, and are used in applications including silos and road-and-rail containers. Booth 2311 — *Porvair Filtration Group Ltd., Hampshire, U.K.*
www.porvairfiltration.com ■

Mary Page Bailey

Note: For more information, circle the 3-digit number on p. 76, or use the website designation.

CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Scott Jenkins

Static Electricity Discharge and Fire Prevention

When flammable or combustible atmospheres are present, uncontrolled discharges of static electricity are potentially dangerous or even catastrophic. A significant portion of industrial explosions and fires are attributable to static electricity each year. In theory, controlling static electricity by grounding potential sources is simple, but in practice, doing so effectively requires thorough knowledge of processes and operations, sound engineering controls, properly specified safety equipment and properly trained operational staff. This column provides information on potential sources of static electrical discharge.

Static risk

Static electricity discharges are possible almost continuously in the chemical process industries (CPI), because static electricity is generated whenever surfaces come into contact and then separate. In most cases, the charging currents generated over time in industrial processes are small — typically no greater than 1×10^{-4} Amps. However, in hazardous areas, even small charges can be a problem when the allowed to accumulate on objects that are not at ground (earth) potential. If no ground is present, voltages in excess of 30 kV can develop. Depending on the capacitance of the object, this may result in significant levels of energy being available for discharge. If the energy equals or exceeds the minimum ignition energy (MIE) of the surrounding flammable atmosphere, the potential for an explosion and fire exist. Many commonly used solvents and other flammable chemicals have MIEs that are relatively low — on the order of 1 mJ or less (Table 1).

Isolated conductors

Isolated conductors are electrically conductive objects that are either inherently or accidentally insulated from earth. During day-to-day operations at industrial facilities, isolated conductors are probably the most likely source of static ignition incidents.

The insulation effectively keeps any static electricity buildup from safely discharging, thereby resulting in accumulation of charge on the object. If the isolated conductor then comes into proximity with another object at a lower potential, energy could be released in the form of an incendive spark.

Isolated conductors may arise from metal flanges, fittings or valves in pipework systems; portable drums, containers or vessels; tanker trucks, railcars and intermediate bulk containers (IBCs); and even people.

Many modern industrial paints, coatings, gaskets, seals and other non-conductive materials are sufficiently insulating, so as to to possibly prevent the proper dissipation of static charge.

Static discharge sources

Static discharges come in several forms, the most important for CPI interests being spark and brush discharges. A spark is a discharge from a charged isolated conductor to another conductor at lower potential. A brush discharge occurs from an electrostatically charged insulator to a grounded conductor.

Typical possible sources of static electrical discharges include the following:

- Spark discharges from any conductive, but not earthed (grounded), bag, bin, drum, container and so on, from which a powder is transferred into a reactor
- Brush discharges from any non-conductive bag, bin, drum, container, and so on, from which a powder is transferred into a reactor
- Spark discharges from any conductive, but not earthed, auxiliary device used in the transfer procedure, including, but not limited to, shovels, funnels, chutes and pipes
- Spark discharges from the operator, if he or she is not adequately earthed
- Brush discharges from any non-conductive auxiliary devices, such as shovels, funnels, chutes and pipes
- Brush discharge from the dust cloud formed within a reactor during powder transfer
- Spark discharges from any conductive, but not earthed, fixtures and fittings within a reactor
- Brush discharges from the charged solvent, suspension or emulsion preloaded in a reactor
- Brush discharges from the powder heap formed on top of the liquid phase within a reactor
- Cone discharges from the powder heap formed on top of the liquid phase
- Liquids flowing through pipelines or filling into drums and tanks
- Persons walking across an insulating floor

Static discharge prevention

Where recommendations tend to converge is in the recommendation to always use conductive or static dissipative materials, and to ensure effective bonding and grounding. For information on grounding best practices and examples of preventing static electrical discharge, consult National Fire Protection Association (NFPA; Quincy, Mass.; www.nfpa.org) standards 77 and 30.

In this context, the term "conductive" would apply to metal materials, such as stainless or carbon steel, aluminum and others; and "static-dissipative" may indicate rubber or plastics that have

TABLE 1. TYPICAL MIE VALUES

Material (gas/vapor or powder/dust)	Minimum Ignition Energy (MIE), mJ
Carbon disulfide	0.009
Methanol	0.14
Xylene	0.20
Toluene	0.24
Propane	0.25
Ethyl acetate	0.46
Zirconium	5.00
Epoxy resin	9.00
Aluminum	10.00
Sugar	30.00
Wheat flour	50.00

Note 1: Minimum ignition energy (MIE) is defined as the minimum energy that can ignite a mixture of a specified flammable material with air or oxygen, measured by a standard procedure.

Note 2: MIE values are provided for guidance only — specific MIE data for any material should be verified. Source: NFPA, IChemE

been formulated with some added semiconductive additives. "Bonding" means linking these objects together by means of a suitably strong conductor (wire), and "grounding" refers to a true "ground/earth" connection that is applied to one or more of the bonded objects.

When one or both of these techniques is applied, and while a low resistance connection between the objects and ground is maintained, operators are able to prevent dangerous levels of static charge from accumulating. In the case of fixed installations such as pipe work, storage tanks and so forth, grounding is relatively simple to implement.

However, these preventive measures are more difficult to implement with portable objects, such as drums, IBCs and tankers. In these instances, purpose-designed temporary grounding and bonding devices must be used, with strict procedures to ensure that they are always in place prior to starting the process. For instance, specific types of clamps and devices for grounding and bonding portable or mobile plant equipment, drums and containers are recommended in NFPA 77, and such grounding clamps and devices generally should employ sharp contact points. These contact points should be made of a wear-resistant material, have positive spring pressure, and be universally adaptable to a wide range of plant objects.

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1. Tyers, G., Avoiding Static Sparks in Hazardous Atmospheres, *Chem. Eng.*, June 2009, pp. 44–49.
2. Glor, M., Preventing Explosions During the Transfer of Solids into Flammable Solvents, *Chem. Eng.*, October 2007, pp. 88–95.

Editor's note. This edition of "Facts at your Fingertips" was adapted from information in the two articles referenced above.

Production of Bio-based Succinic Acid

By Intratec Solutions

Succinic acid is an important industrial chemical that is traditionally derived from petroleum feedstocks. It can be used in several areas — from high-value niche applications, such as food, beverages and pharmaceuticals, to large-volume applications, such as plasticizers, resins and coatings. However, the current market for succinic acid is limited to specialized areas because of its costly production process.

Bio-based succinic acid, produced from renewable feedstocks, appears to be an alternative to the petroleum-derived chemical and may have advantages surrounding concerns about rising atmospheric greenhouse gas (GHG) concentrations and volatile crude oil prices. Bio-succinic acid is chemically equivalent to conventionally produced succinic acid, and is suitable for the same applications. For more on bio-based succinic acid, see *Chem. Eng.*, August 2013, pp. 14–17.

The process

In the process depicted in Figure 1, succinic acid is obtained via microbial fermentation of glucose from sugarcane juice. The process steps and equipment were compiled based on publically available information from the scientific literature.

Sugar inversion. The sugar consumed in this fermentation-based process is glucose. It is obtained by the inversion of sucrose through its hydrolysis to glucose and fructose. This is achieved by subjecting the juice containing sucrose to an acidic medium by addition of hydrochloric acid (HCl). After inversion, the pH is adjusted with sodium carbonate (Na_2CO_3) and the stream is cooled before being sent to the fermentation step.

Fermentation. Glucose is converted to succinic acid through an anaerobic fermentation supplied with carbon dioxide. The microorganism culture is prepared for inoculation in a two-stage seed train. Carbon dioxide is compressed, filtered and cooled before being fed into the fermenter. A solution of ammonia (NH_3) is added to the fermenters to maintain a pH level of about 7.

Cell separation. The fermentation broth is sent to surge tanks and then to centrifuges in order to completely remove cell biomass. Ultrafiltration is used to remove the remaining contaminants, such as cell debris and precipitated proteins. Following that, the aqueous solution, free of microorganisms, is sent to the product recovery and purification area.

Recovery and purification. In this stage, a decolorization process is performed with the addition of activated carbon. Then, the mixture is filtered to separate the activated carbon. The aqueous phase is sent to a vacuum-distillation column, where volatile byproducts and some water are removed. This distillation leads to a more concentrated succinic acid stream. The succinic acid product is then crystallized at low temperature. HCl is used to adjust pH, allowing selective crystallization of succinic acid. Succinic acid crystals are washed with water in a filter and dried with hot air. Part of the succinic acid product that is lost in the filtrate is recycled to the distillation column.

Economic performance

An economic evaluation of the bio-based succinic acid process was conducted. The following assumptions were taken into consideration:

- A 77,000 ton/yr unit erected on the U.S. Gulf Coast (the process equipment is represented in the simplified flowsheet below)
- Storage of product is equal to 30 days of operation, and there is no storage for feedstock
- Outside battery limits (OSBL) units considered: steam boilers, cooling towers and ammonium refrigeration system

The estimated capital investment (including total fixed investment, working capital and other capital expenses) is about $260 million, and the operating expenses are about $2,200/ton of product (Figure 2).

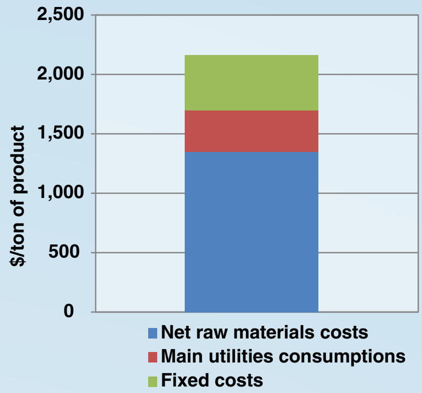

FIGURE 2. The operating expenses for bio-succinic acid are broken down here

Beginning with high-value applications, bio-succinic acid has the potential to become a key building block for commodity chemicals, since consumers of end-use products are increasingly demanding more eco-friendly products. Also, further development in bio-based succinic acid processes will likely lead to more cost-effective production, resulting in an increase in the demand for this product compared to the costly petroleum-based succinic acid.

Based on these features, several new projects for producing bio-based succinic acid have begun operations, and others are planned in the near future, thus growing the worldwide production capacity for this key industry chemical. ■

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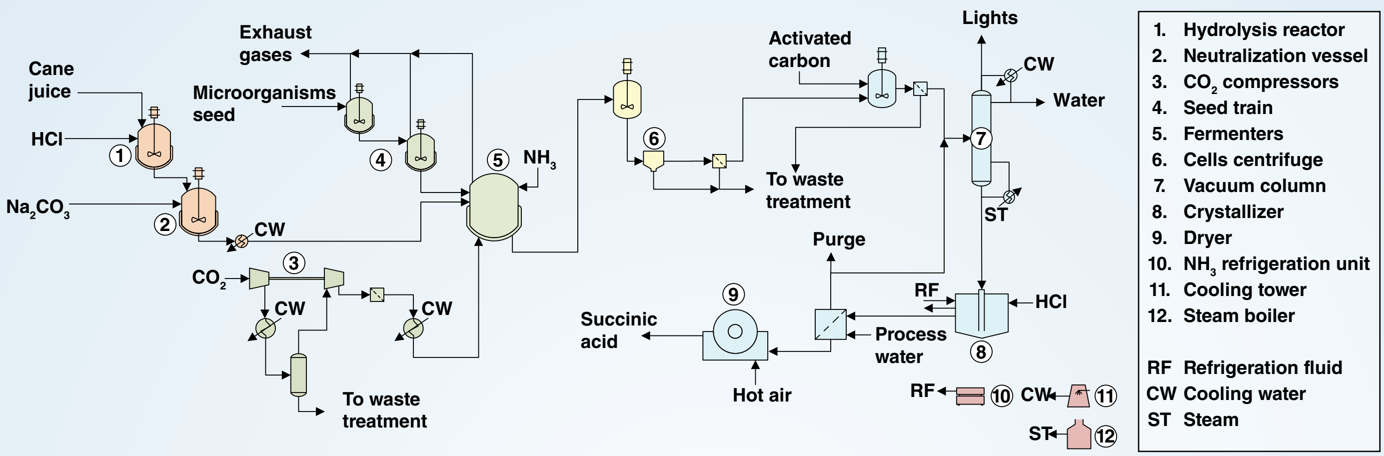

FIGURE 1. Bio-succinic acid is produced via the fermentation of glucose

Overcoming Solids Caking with Flow Aids

A wide range of passive and active flow aids are available to assist gravity flow of solids from bins and hoppers

Joseph Marinelli
Solids Handling Technologies, Inc.

FIGURE 1. Many solids exhibit caking or packing properties when under pressure, such as that seen in a bin or silo

FIGURE 2. The Jenike Shear Test Method, for determining a solid's flow properties, is used in an ASTM standard

Using gravity to initiate flow in the discharge of solid materials from bins and hoppers is the simplest, and often best, approach to solving solids-handling challenges. However, not all solid materials flow well by gravity alone. The propensity for fine solid materials to cake can lead to flow problems that will adversely affect your process. For situations where material caking disrupts gravity flow, a range of flow aid approaches are available to solve a variety of flow issues. This article discusses the operation of passive and active flow aids, and points out considerations for their use.

PARTICLE CAKING

Cohesive strength is a characteristic of many materials, and fine solids tend to cake, agglomerate and pack because of it. But what is cohesive strength? Most of us understand it intuitively — gently reach into a box of laundry detergent and the detergent sifts or flows through our fingers, but squeeze or compact the material, and it retains its shape and no longer flows over our fingers (Figure 1). This effect is due to compaction or consolidation pressure, which is a key factor in bulk-solids handling. Consider that inside a bin or silo, the pressures acting on the solids are very high and can easily cause the material to consolidate.

Measuring the flow properties of a bulk solid is critical to understanding how it will flow in a new system, or why it is troublesome in an existing system. Knowing the type of flow pattern that develops in a bin or silo is a prerequisite to reliable handling. Two major types of flow patterns can develop in solids flow: funnel flow and mass flow. In funnel flow, whenever any material is discharged from a container, some material moves while the rest remains stagnant. Funnel flow can lead to ratholing, erratic flow, flooding and segregation. When material flows in mass flow mode, all the material moves whenever any is withdrawn from the bin or hopper. This means that the material is sliding at the walls of the container and segregation is minimized, while ratholing and flooding generally do not occur.

Several test methods are available to identify a material's flow properties. The Jenike Shear Test method is the most important and has been the standard in the U.S. and Europe. The ASTM International consensus standard D 6128-06 for measuring bulk-solids flow properties is based on it. The method is named after Andrew Jenike, a pioneer of the theory of bulk solids flow. Jenike's scientific approach to the storage and flow of bulk solids, developed in the 1950s, remains relevant today.

The device used for the Jenike Shear Test is considered a linear direct shear tester (Figure 2). Other devices include Schulze's Ring Shear Tester, Brookfield Annular Shear Tester, Peschl's Rotary Shear Tester and the Freeman Tester. Keep in mind that all of these devices compare their results to the Jenike Shear Test results.

Once information is gathered on the flow properties of a solid material, it may be necessary to select a gravity flow aid to overcome particle caking. The following discussion of flow aids categorizes the devices into two types: active and passive.

MECHANICAL FLOW AIDS

Mechanical, or active devices include vibrating dischargers, vibrators, agitations and forced-extraction devices. Air-operated devices, such as air blasters, air pads, air fluidizers and so on, are also included in the active flow-aid discussion.

Vibrating bin discharger

Some mechanical flow-aid devices rely on internal components to force material to flow. Probably the most commonly used device is the vibrating bin discharger (Figure 3). A

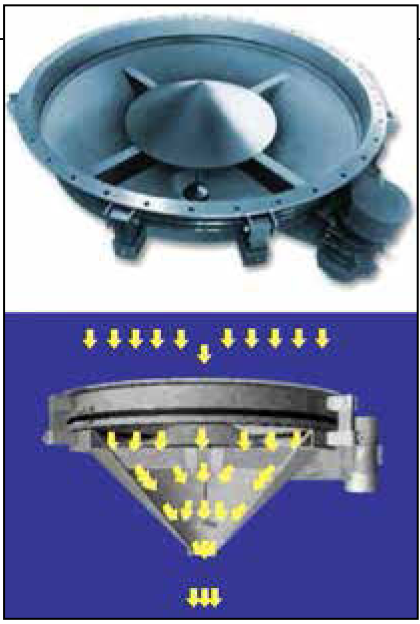

FIGURE 3. Eccentric weights are at work in a vibrating bin discharger

FIGURE 4. Vibrators can be mounted on the side of a bin to initiate flow

FIGURE 5. Agitators produce a downward flow of solids into a discharge auger

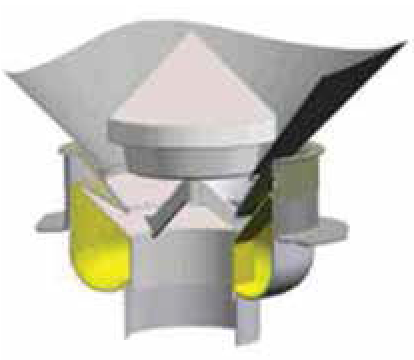

FIGURE 6. A cone unloader has a vibrating cone that extends into the product to initiate flow

vibrating discharger can accommodate hopper openings from about 3 to 15 ft and is intended to keep material completely live over a hopper outlet's entire cross-sectional area. This type of device is hung from a storage bin by rubber bushed links, and incorporates a rubber skirt to prevent leakage and to isolate the bin from the vibrations. Vibration is transmitted through an outer shell and into an internal dome or cone-shaped baffle by a motor with eccentric weights. A cohesive bulk solid can be broken up and made to flow, depending on the amplitude of vibration applied.

Several issues should be considered when using a vibrating bin discharger, including the following:

- It must discharge over its entire cross-sectional area and be operated according to manufacturer instructions, which usually require it to be cycled on and off intermittently. Otherwise, small preferential flow channels will form, affecting solids flow and potentially causing structural problems
- If solids in a bin are flowing in a funnel-flow pattern, the diameter of the discharger must be larger than the ratholing capability of the material (as long as the discharger cross-section is fully live)
- A discharger cannot control solids flowrate and it is not a feeder. As such, it requires a feeder to control the discharge rate to the process or system
- Pressure-sensitive materials usually do not flow well through dischargers. They tend to pack in the annulus created by the baffle and outer shell

Vibrators

Vibrators have long been used to enhance material flow. Sledgehammers or mallets are probably the most common flow aid of this type used. These can be the the least expensive way to encourage flow in a bin (and in some cases modify the shape of a bin). There are however, vibrators available that will essentially replace the sledgehammer.

Vibrators can be mounted on the side of a bin or chute in an attempt to initiate flow. These vibrators can be air- or electrically operated and come in all shapes and sizes. Rotary, piston, turbine, linear, electromagnetic, eccentric and several others are specific types of vibrators (Figure 4). Some types are designed to provide high-frequency, low-amplitude vibration to a surface. Others are used to generate high-amplitude vibrations, such as those required to provide a "thump." Battering rams are even used to bang the side of a large bin in order to move material.

However, vibrators should be used with caution. Here are a number of considerations:

- The material in the bin should not be pressure-sensitive. If the material can be squeezed to form a "snowball," it is likely to pack inside the bin, due to vibration
- Do not operate a vibrator unless the solid material has somewhere to move. The feeder must be operating or the gate opened; otherwise packing will occur
- Chutes are a good place to mount vibrators, as they will enhance flow down a shallow chute
- Be aware of the vibrator's effect on the structural integrity of the bin

Agitation

Devices that agitate a solid product are available, and are typically composed of multiple segmented helical sections that slowly rotate within the body of the discharger (Figure 5). This produces a downward flow into a discharge auger that controls the rate of withdrawal. For agitator-type flow aids, consider the following:

- The conditioning auger operates slowly (about 1–2 rpm) to minimize consolidation
- The size of the unit is usually based on the arching dimensions of the material
- These flow aids can have difficulty with flaky or cohesive materials

Cone unloading

A cone unloader is a device similar to a vibrating-bin discharger but it has an internal cone that is raised into the product and vi-

FIGURE 7. Traveling-auger unloaders work well with woodchips, biomass and granular or flaky materials

FIGURE 8. Cone-bottom systems have scews that rotate around their own axes, while also advancing around the silo

FIGURE 9. Giro whips are powered by compressed air and manipulated by operators

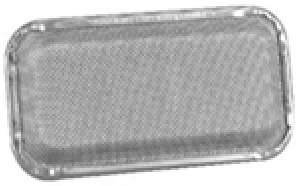

FIGURE 10. Airpads discharge air at bin walls to provide localized fluidization of products

brated to initiate flow (Figure 6). This device uses a vibrating cone that is intended to promote mass flow and break bridges. It can be used as a gate as well as a discharging device. Cone unloaders are dust-tight, and if they fail, they will fail safe-closed.

Forced extraction

Traveling-auger unloaders have been in use for years and are typically used to discharge solids from flat-bottomed bins and silos. These heavy-duty, track-driven systems are designed for continuous operation under the most challenging conditions (Figure 7). Traveling augers cause solid material to discharge, dragging products to a centered discharge point. Traveling augers work well with woodchips, biomass and granular or flaky materials. This type of flow aid occupies minimal headroom.

Cone-bottom systems

Cone-bottom storage and reclaim systems work for materials with moderate flow characteristics (Figure 8). The screw rotates about its own axis, moving material toward the center of the silo outlet. At the same time, the screw slowly advances, sweeping around the entire silo hopper. Material is discharged to the center of the silo hopper, then flows down through a central chute below the hopper and into a discharge auger or conveyor for transfer out of the silo and to the next step in the material handling process. The cone bottom unloader uses a rotating auger to provide product withdrawal and a collecting auger to discharge material away from the silo. This type of flow aid handles dry meals, chemicals, plastics and small-particle wood waste.

Rotating-arm unloader

Some materials, such as marl limestone, sludge and clay, do not respond well to vibration. However, a rotating-arm discharger may be used. These devices use a traveling arm to discharge product. They drag material to a central discharge point. Advantages of the rotating-arm unloader include first-in, first-out material flow, gentle handling of material, and repeatable, accurate discharge rates, creating consistency in operation. The rotating arm unloader works well with sticky materials, such as synthetic gypsum, sludge and others.

Cleanout devices

Cardox systems use a tube or cartridge that is filled with liquid carbon dioxide. When the cartridge is energized by the application of a small electrical charge, the chemical inside instantly converts the liquid CO_2 to gas. This conversion expands the CO_2 volume and builds up pressure inside the tube until it causes the rupture disc at the end of the tube to burst. This releases the CO_2 (now 6,000 times its original volume) through a special discharge nozzle to create a powerful heaving force, at pressures up to 40,000 psi. Keep the following in mind:

- The rupture (shear) disc bursts, releasing a heaving mass of carbon dioxide, which breaks apart the surrounding solid material
- This is a dangerous approach to encouraging flow from a bin, and is used in specialized situations
- Cleanout devices can create large boulders of solid material that, when falling, can cause structural damage to equipment

Giro whips (Figure 9) are another type of cleanout device. They are powered by compressed air and maneuvered by an operator who manipulates the cleaning head. They use a variety of whips and cutting edges. An advantage of this type of device is that they are mobile and can be easily positioned at the cleaning location.

Aeration

Air pads (Figure 10) have been used for years and work by discharging air along the walls of bins and hoppers. They provide localized fluidization to aid flow, and require several pads to be effective. Users must be careful, because the pads may also obstruct flow.

Fluidizers are a popular means of achieving locally fluidize product along the walls of a hopper (Figure 11). Fluidizers basically work by undercutting solid material to provide localized fluidization. They can be mounted externally so that aid can be obtained without emptying the bin.

Air blasters inject high-pressure air into a bin or silo that has trouble

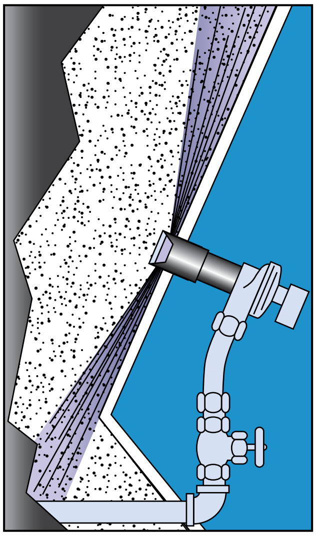

FIGURE 11. Fluidizers are an alternate method to generate localized fluidization, but they are mounted externally

FIGURE 12. Cone-in-cone devices are designed to convert funnel-flow patterns to mass-flow solids flow

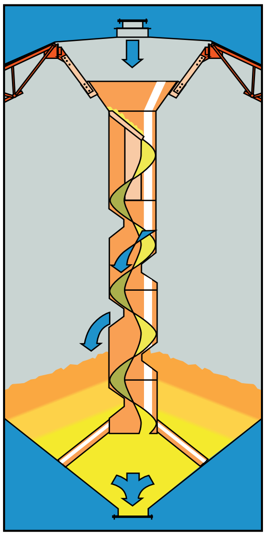

FIGURE 13. Letdown chutes lower solid material gently into the bin

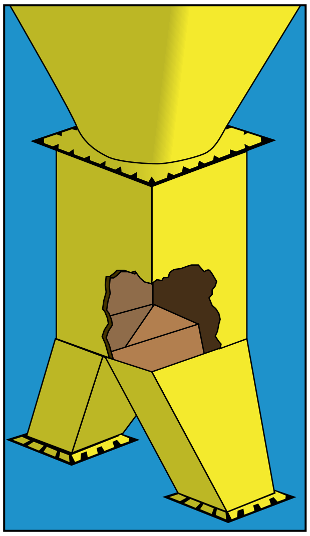

FIGURE 14. Splitters prevent stagnation of material when one discharge stream is stopped

with arching, ratholing or both. An air blaster uses air or nitrogen that is stored in a tank at about 80 to 100 psi. Air blasters also have a piston-sealed exhaust and quick-acting valve to fire the high-pressure air at an arch or rathole. The expanding air breaks bridges and causes material to flow.

NON-MECHANICAL AIDS

Non-mechanical solids-flow aids are also known as passive aids, and there are several types. Among them are powders and chemicals that can be added to some solids to improve their flowability. Flow aid chemicals, such as fumed silica, can improve flow, reduce caking and improve storage stability.

Freeze conditioning agents

These flow aids are available for products that are exposed to subfreezing conditions. Freeze-conditioning agents interfere with the bonds between the solid material and frozen moisture, creating a slush instead of a frozen block. Freeze-conditioning agents serve to reduce a solid's arching dimensions.

Cone-in-cone

This approach to aiding solids flow involves a conical hopper mounted within another larger conical hopper. The design is intended to minimize hopper height and promote mass flow (Figure 12). The inner cone, which is open at the top and bottom, is designed for mass flow and it forces the material to flow along the walls of the shallow outer cone. The cone-in-cone design is used to perform the following:

- Help convert a funnel flow pattern to mass flow
- Prevent segregation
- Promote blending

The surface finish of the hoppers is critical to ensure mass flow.

Letdown chute

When dealing with solid materials that are fragile and tend to break down easily when handled using bins and feeders, a letdown chute may be used to minimize attrition (Figure 13). When using the letdown chute, the material is deposited in the top of the spiral chute, and is lowered to the bottom of the bin, where it gently spills out of the openings provided.

Splitter

Often, a process requires two discharge streams to provide product to two different processes, conveyors and so on. Most of the time, a pant-leg-type hopper is used to discharge to the two points. This approach will work if both legs of the pant-leg hopper are discharging simultaneously. If, however, one leg of the pant leg is stopped, most of the material in the bin becomes stagnant.

The preferred way to provide multiple discharge points is to use a splitter concept (Figure 14). If one leg becomes blocked, the vertical section above it will allow the preferential flow channel that forms due to the flowing leg, to expand within it such that the product at the outlet is fully live. This prevents the stagnation created by the stopped pant-leg hopper. ■

Edited by Scott Jenkins

Author

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Solids Drying: Basics and Applications

Several types of batch and continuous dryers exist in the CPI for removing moisture from solids

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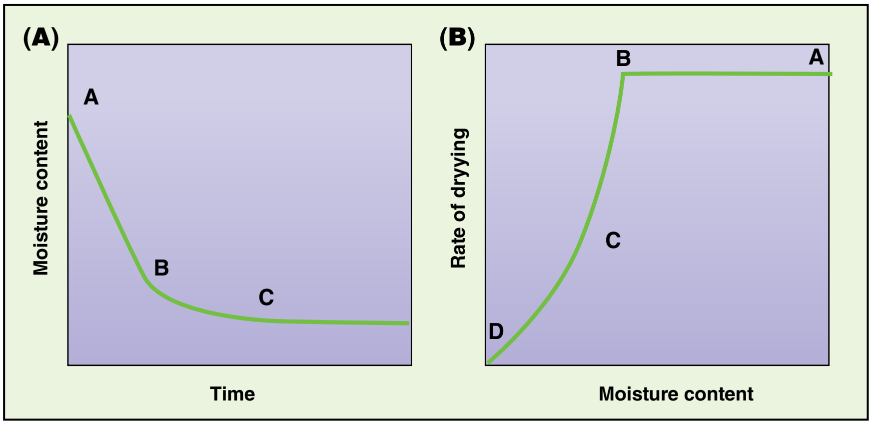

FIGURE 1. Segment AB of the graph represents the constant-rate drying period, while segment BC is the falling-rate period

Adjustment and control of moisture levels in solid materials through drying is a critical process in the manufacture of many types of chemical products. As a unit operation, drying solid materials is one of the most common and important in the chemical process industries (CPI), since it is used in practically every plant and facility that manufactures or handles solid materials, in the form of powders and granules.

The effectiveness of drying processes can have a large impact on product quality and process efficiency in the CPI. For example, in the pharmaceutical industry, where drying normally occurs as a batch process, drying is a key manufacturing step. The drying process can impact subsequent manufacturing steps, including tableting or encapsulation and can influence critical quality attributes of the final dosage form.

Apart from the obvious requirement of drying solids for a subsequent operation, drying may also be carried out to improve handling characteristics, as in bulk powder filling and other operations involving powder flow; and to stabilize moisture-sensitive materials, such as pharmaceuticals.

This article provides basic information on the sometimes complicated heat- and mass-transfer processes that are important in drying, and discusses several technologies used to accomplish the task.

MECHANISM OF DRYING

Drying may be defined as the vaporization and removal of water or other liquids from a solution, suspension, or other solid-liquid mixture to form a dry solid. It is a complicated process that involves simultaneous heat and mass transfer, accompanied by physicochemical transformations. Drying occurs as a result of the vaporization of liquid by supplying heat to wet feedstock, granules, filter cakes and so on. Based on the mechanism of heat transfer that is employed, drying is categorized into direct (convection), indirect or contact (conduction), radiant (radiation) and dielectric or microwave (radio frequency) drying.

Heat transfer and mass transfer are critical aspects in drying processes. Heat is transferred to the product to evaporate liquid, and mass is transferred as a vapor into the surrounding gas. The drying rate is determined by the set of factors that affect heat and mass transfer. Solids drying is generally understood to follow two distinct drying zones, known as the constant-rate period and the falling-rate period. The two zones are demarcated by a break point called the critical moisture content.

In a typical graph of moisture content versus drying rate and moisture content versus time (Figure 1), section AB represents the constant-rate period. In that zone, moisture is considered to be evaporating from a saturated surface at a rate governed by diffusion from the surface through the stationary air film that is in contact with it. This period depends on the air temperature, humidity and speed of moisture to the surface, which in turn determine the temperature of the saturated surface. During the constant rate period, liquid must be transported to the surface at a rate sufficient to maintain saturation.

At the end of the constant rate period, (point B, Figure 1), a break in the drying curve occurs. This point is called the critical moisture content, and a linear fall in the dry-

TABLE 1. COMPARISON OF DIRECT AND INDIRECT DRYERS [4]

Property	Direct/adiabatic dryer (convective type)	Indirect/non-adiabatic contact dryer (conductive type)
Carrier gas	Uses sensible heat of gas that contacts the solid to provide the heat of vaporization of the liquid	Little or no carrier gas is required to remove the vapors released from the solids
Heat transfer	Heat transfer medium is in direct contact with the surface of the material to be dried	Heat needed to vaporize the solvent is transferred through a wall
Risk of cross contamination	Persists	Avoided, as the heat transfer medium does not contact the product
Solvent recovery	Difficult as there is a large volume of gas to be cooled to recover the solvent	Easier because of limited amount of non-condensable gas encountered
Operation under vacuum	Not possible	Allows operation under vacuum, ideal for heat sensitive materials
Dusting	High	Minimized because of small volume of vapors involved
Explosion hazard	Higher rate	Easier to control as vapors can be easily condensed
Handling of toxic materials	Not suitable	Suitable because of low gas flow
Energy efficiency	Significant energy lost through exhaust gas	Higher energy efficiency as the energy lost through the exhaust gas is greatly reduced
Evaporation and production rates	Higher than contact dryers	Drying rates are limited by heat transfer area, lower production rates
Cost	High	Higher initial cost; difficult to design, fabricate and maintain

ing rate occurs with further drying. This section, segment BC, is called the first falling-rate period. As drying proceeds, moisture reaches the surface at a decreasing rate and the mechanism that controls its transfer will influence the rate of drying. Since the surface is no longer saturated, it will tend to rise above the wet bulb temperature. This section, represented by segment CD in Figure 1 is called the second falling-rate period, and is controlled by vapor diffusion. Movement of liquid may occur by diffusion under the concentration gradient created by the depletion of water at the surface. The gradient can be caused by evaporation, or as a result of capillary forces, or through a cycle of vaporization and condensation, or by osmotic effects.

The capacity of the air (gas) stream to absorb and carry away moisture determines the drying rate and establishes the duration of the drying cycle. The two elements essential to this process are inlet air temperature and air flowrate. The higher the temperature of the drying air, the greater its vapor holding capacity. Since the temperature of the wet granules in a hot gas depends on the rate of evaporation, the key to analyzing the drying process is psychrometry, defined as the study of the relationships between the material and energy balances of water vapor and air mixture.

Drying endpoint

There are a number of approaches to determine the end of the drying process. The most common one is to construct a drying curve by taking samples during different stages of drying cycle against the drying time and establish a drying curve. When the drying is complete, the product temperature will start to increase, indicating the completion of drying at a specific, desired product-moisture content. Karl Fischer titration and loss on drying (LOD) moisture analyzers are also routinely used in batch processes. The water vapor sorption isotherms are measured using a gravimetric moisture-sorption apparatus with vacuum-drying capability.

For measuring moisture content in grain, wood, food, textiles, pulp, paper, chemicals, mortar, soil, coffee, jute, tobacco, rice and concrete, electrical-resistance-type meters are used. This type of instrument operates on the principle of electrical resistance, which varies minutely in accordance with the moisture content of the item measured. Dielectric moisture meters are also used. They rely on surface contact with a flat plate electrode that does not penetrate the product.

For measuring moisture content in paper rolls or stacks of paper, advanced methods include the use of the radio frequency (RF) capacitance method. This type of instrument measures the loss, or change, in RF dielectric constant, which is affected by the presence or absence of moisture.

TYPES OF DRYERS

Adiabatic dryers are the type where the solids are dried by direct contact with gases, usually forced air. With these dryers, moisture is on the surface of the solid. Non-adiabatic dryers involve situations where a dryer does not use heated air or other gases to provide the energy required for the drying process

Dryer classification can also be based on the mechanisms of heat transfer as follows:

- Direct (convection)
- Indirect or contact (conduction)
- Radiant (radiation)
- Dielectric or microwave (radio frequency) drying

Direct, or adiabatic, units use the sensible heat of the fluid that contacts the solid to provide the heat of vaporization of the liquid.

With adiabatic dryers, solid materials can be exposed to the heated gases via various methods, including the following:

- Gases can be blown across the surface (cross circulation)
- Gases can be blown through a bed

TABLE 2. CLASSIFICATION OF DRYERS [5]	
Criterion	**Types**
Mode of operation	Batch Continuous*
Heat input type	Convection*, conduction, radiation, electromagnetic fields, combination of heat transfer modes Intermittent or continuous* Adiabatic or non-adiabatic
State of material in dryer	Stationary Moving agitated, dispersed
Operating pressure	Vacuum* Atmospheric
Drying medium (convection)	Air* Superheated steam Fluegases
Drying temperature	Below boling temperature* Above boiling temperature Below freezing point
Relative motion between drying medium and solids	Co-current Countercurrent Mixed flow
Number of stages	Single* Multistage
Residence time	Short (<1 min) Medium (1–60 min) Long (>60 min)
* Most common in practice	

of solids (through-circulation); used when solids are stationary, such as wood, corn and others

- Solids can be dropped slowly through a slow-moving gas stream, as in a rotary dryer
- Gases can be blown through a bed of solids that fluidize the particles. In this case, the solids are moving, as in a fluidized-bed dryer
- Solids can enter a high-velocity hot gas stream and can be conveyed pneumatically to a collector (flash dryer)

Non-adiabatic dryers (contact dryers) involve an indirect method of removal of a liquid phase from the solid material through the application of heat, such that the heat-transfer medium is separated from the product to be dried by a metal wall. Heat transfer to the product is predominantly by conduction through the metal wall and the impeller. Therefore, these units are also called conductive dryers.

Although more than 85% of the industrial dryers are of the convective type, contact dryers offer higher thermal efficiency and have economic and environmental advantages over convective dryers. Table 1 compares direct and indirect dryers, while Table 2 shows the classification of dryers based on various criteria.

Batch dryers

The following are descriptions of various types of batch dryers.

Tray dryers. This dryer type operates by passing hot air over the surface of a wet solid that is spread over trays arranged in racks. Tray dryers are the simplest and least-expensive dryer type. This type is most widely used in the food and pharmaceutical industries. The chief advantage of tray dryers, apart from their low initial cost, is their versatility. With the exception of dusty solids, materials of almost any other physical form may be dried. Drying times are typically long (usually 12 to 48 h).

Vacuum dryers. Vacuum dryers offer low-temperature drying of thermolabile materials or the recovery of solvents from a bed. Heat is usually supplied by passing steam or hot water through hollow shelves. Drying temperatures can be carefully controlled and, for the major part of the drying cycle, the solid material remains at the boiling point of the wetting substance. Drying times are typically long (usually 12 to 48 h).

Fluidized-bed dryers. A gas-fluidized bed may have the appearance of a boiling liquid. It has bubbles, which rise and appear to burst. The bubbles result in vigorous mixing. A preheated stream of air enters from the bottom of the product container holding the product to be dried and fluidizes it. The resultant mixture of solids and gas behave like a liquid, and thus the solids are said to be fluidized. The solid particles are continually caught up in eddies and fall back in a random boiling motion so that each fluidized particle is surrounded by the gas stream for efficient drying, granulation or coating purposes. In the process of fluidization, intense mixing occurs between the solids and air, resulting in uniform conditions of temperature, composition and particle size distribution throughout the bed.

Freeze dryers. Freeze-drying is an extreme form of vacuum drying in which the water or other solvent is frozen and drying takes place by subliming the solid phase. Freeze-drying is extensively used in two situations: (1) when high rates of decomposition occur during normal drying; and (2) with substances that can be dried at higher temperatures, and that are thereby changed in some way.

Microwave vacuum dryers. High-frequency radio waves with frequencies from 300 to 30,000 MHz are utilized in microwave drying (2,450 MHz is used in batch microwave processes). Combined microwave-convective drying has been used for a range of applications at both laboratory and industrial scales. The bulk heating effect of microwave radiation causes the solvent to vaporize in the pores of the material. Mass transfer is predominantly due to a pressure gradient established within the sample. The temperature of the solvent component is elevated above the air temperature by the microwave heat input, but at a low level, such that convective and evaporative cooling effects keep the equilibrium temperature below saturation. Such a drying regime is of particular interest for drying temperature-sensitive materials. Microwave-convective processing typically facilitates a 50% reduction in drying time, compared to vacuum drying.

Source: Anhydro

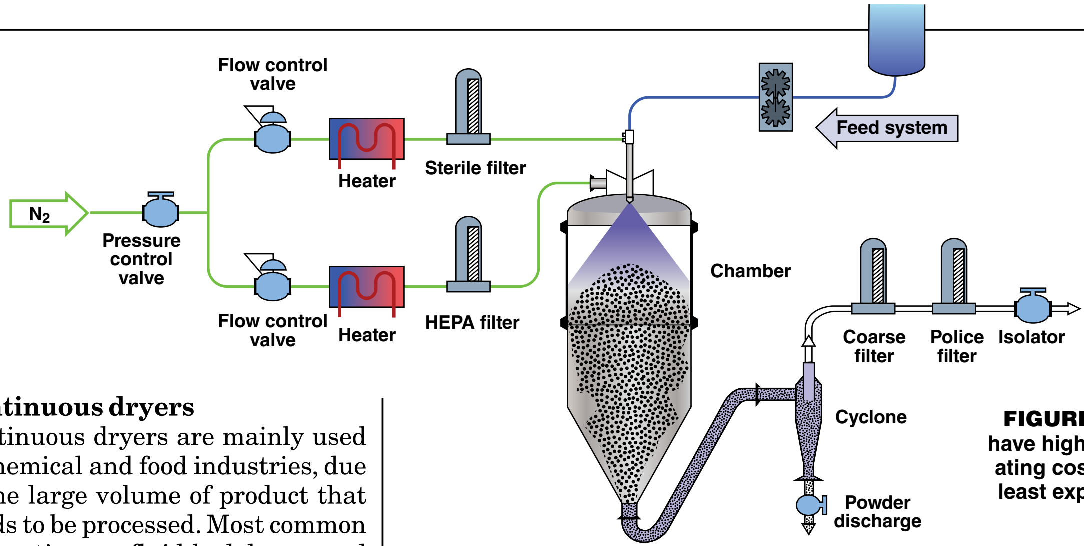

FIGURE 2. Spray dryers have high capital and operating costs, but can be the least expensive method at large scales

Continuous dryers

Continuous dryers are mainly used in chemical and food industries, due to the large volume of product that needs to be processed. Most common are continuous fluid-bed dryers and spray dryers. There are other dryers, depending on the product, that can be used in certain industries — for example, rotary dryers, drum dryers, kiln dryers, flash dryers, tunnel dryers and so on. Spray dryers are the most widely used in chemical, dairy, agrochemical, ceramic and pharmaceutical industries.

Spray dryer. The spray-drying process can be divided into four sections: atomization of the fluid, mixing of the droplets, drying, and, removal and collection of the dry particles (Figure 2). Atomization may be achieved by means of single-fluid or two-fluid nozzles, or by spinning-disk atomizers. The flow of the drying gas may be concurrent or countercurrent with respect to the movement of droplets. Good mixing of droplets and gas occurs, and the heat- and mass-transfer rates are high. In conjunction with the large interfacial area conferred by atomization, these factors give rise to very high evaporation rates. The residence time of a droplet in the dryer is only a few seconds (5–30 s). Since the material is at wet-bulb temperature for much of this time, high gas temperatures of 1,508 to 2,008°C may be used, even with thermolabile materials. For these reasons, it is possible to dry complex vegetable extracts, such as coffee or digitalis, milk products, and other labile materials without significant loss of potency or flavor. The capital and running costs of spray dryers are high, but if the scale is sufficiently large, they may provide the cheapest method.

Dryer efficiency

With increasing concern about environmental degradation, it is desirable to decrease energy consumption in all sectors. Drying has been reported to account for anywhere from 12 to 20% of the energy consumption in the industrial sector. Drying processes are one of the most energy-intensive unit operations in the CPI.

One measure of efficiency is the ratio of the minimum quantity of heat that will remove the required water to the energy actually provided for the process. Sensible heat can also be added to the minimum, as this added heat in the material often cannot be economically recovered. Other newer technologies have been developed, such as sonic drying, superheated steam, heat-pump-assisted drying and others.

Concluding remarks

Drying is an essential unit operation used in various process industries. The mechanism of drying is well understood as a two-stage process and depends on the drying medium and the moisture content of the product being dried.

Batch dryers are common in chemical and pharmaceutical industries, while continuous dryers are routinely used where large production is required. Since the cost of drying is a significant portion of the cost of manufacturing a product, improving efficiency or finding alternative drying routes is essential. ■

Edited by Scott Jenkins

Further reading

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Getting down to the nitty-gritty

Effective handling and processing of solid materials are vital to the chemical process industries (CPI). Engineers plagued with blocked conveyors, abraded mixer internals or potentially explosive dusts may regret that fact, and it is true that liquids are frequently easier to move, store, mix, heat, and meter. Yet, for a significant proportion of the CPI, the product takes the form of a powder or granular solid. For the rest, solids are sure to crop up somewhere in the process – as water-treatment chemicals on a pharmaceutical plant, for instance, or sulfur pastilles at a refinery. This brand-new Special Advertising Section in CE addresses engineers' need to handle and process solids in many different ways. Their presentations will inform and inspire you. ■

Inside

This system dries liquids to powder continuously

Thin-film dryers from GIG Karasek are versatile, and ideal for sensitive products

Thin-film dryer unit from GIG Karasek

Thin-film drying technology from **GIG Karasek** can be used for continuous drying of suspensions, municipal sludges, slurries, pastes, wet solids, filter cakes and chemical products. It is also suitable for heat-sensitive products, such as polymers, foods and pharmaceuticals.

A thin-film dryer is a special type of wiped-film evaporator. The product to be dried is distributed over the circumference of the heating surface to form a downward-flowing thin film of liquid that is stirred by a specially shaped rotor system to create optimal turbulence. These dryers can produce dry powder from a liquid feed. They can be used either alone, or as a pre- or post-dryer combined with other equipment. Horizontal thin-film dryers are ideal for drying slurries and pastes, while their vertical counterparts are preferred for continuous drying of liquids to wet solids in a single step. Both types feature short residence times (can be influenced), low holdup, self-cleaning characteristics, and low energy consumption. Closed-system operation allows toxic and dangerous products such as solvents to be handled safely.

www.gigkarasek.com

Mix solids with liquids, solidify and transport

Sandvik Process Systems offers solutions for handling mixtures of solids and liquids

Engineering company **Sandvik Process Systems** has developed upstream dosing, mixing and grinding solutions that enable the combination of liquid and solid products into suspensions ready for solidification on its Rotoform pastillation system.

This ability to supply complete mixing, solidification and handling systems enables the cost-effective production of speciality products such as multi-nutrient fertilizers.

A typical plant will use precise dosing and weighing together with a mixer and grinder to combine liquid melts and solid materials into a suspension. The suspension then undergoes further dispensing and grinding before it reaches the Rotoform.

Sandvik's Rotoform pastillation system consists of a heated, cylindrical stator and a perforated rotating shell that deposits molten droplets onto a continuously running steel belt. Cooling water is sprayed against the underside of the solid steel belt and the resulting transfer of heat converts the liquid droplets into solid pastilles.

This indirect heat exchange ensures that there is no risk of cross-contamination between the end product and the cooling medium. Dust is minimal, so no dedicated scrubbing is required for air purification, and energy consumption is low.

Pastillation is just one of the technologies on offer

Sandvik also supplies a full range of downstream systems including elevators, conveyors, storage silos, bag filling systems and loading equipment.

www.processsystems.sandvik.com

Ultra-high speed powder dispersion made simple

Ross SLIM Technology employs high shear for rapid and complete mixing of powders into liquids, avoiding agglomerates and dust formation

Ross SLIM technology as a packaged skid

The **Ross** Solids/Liquid Injection Manifold (SLIM) is a technology for dispersing challenging powders like fumed silica, gums, thickeners and pigments using a specially modified high shear rotor/stator generator.

In both batch and inline designs, the SLIM is easy to retrofit into almost any process. In an inline set-up, the SLIM mixer pumps liquid from the recirculation tank while simultaneously drawing powders from a hopper. As the liquid stream enters the rotor/stator assembly, it immediately encounters the powder injection at the high shear zone. The mixture is then expelled through the stator at high velocity and recirculated back into the tank. In just a few short turnovers, solids are completely dissolved or reduced to the desired particle size.

This method for high-speed powder injection is ideal for dispersing small concentrations of hard-to-wet solids like CMC or xanthan gum (>5%). It is equally effective for solid loadings as high as 70%, as in the case of titanium dioxide or magnesium hydroxide slurries. By introducing solids sub-surface where they are instantly subjected to vigorous agitation, issues like floating powders, excessive dusting and formation of stubborn agglomerates ("fish eyes") are eliminated. Because the SLIM generates its own vacuum for powder induction and does not rely on external eductors or pumps, it is free of clogging and simple to operate.

Several models are available including automated skid packages where the SLIM mixer is piped to a jacketed tank and supplied with flowmeters, load cells, solenoid valves, level sensors and thermocouples all integrated into a PLC Recipe Control Panel. Each ingredient addition and process step can be pre-programmed so that mixer speed, mixing time, temperature, composition and batch weight are accurately replicated in every run.

Established in 1842, Ross is one of the oldest and largest manufacturers of process equipment in the world. Specializing in mixing, blending, drying and dispersion equipment, Ross builds standard and custom designs for virtually any process or application. **www.highshearmixers.com**

Handle virtually any bulk solid material

Flexicon stand-alone equipment and automated plant-wide systems convey, discharge, condition, fill, dump and/or weigh batch bulk materials dust-free

Flexicon Corporation engineers and manufactures a broad variety of equipment that handles virtually any bulk material, from large pellets to sub-micron powders, including free-flowing and non-free-flowing products that pack, cake, plug, smear, fluidize, or separate.

The line includes: Flexible Screw Conveyors, Tubular Cable Conveyors, Pneumatic Conveying Systems, Bulk Bag Unloaders, Bulk Bag Conditioners, Bulk Bag Fillers, Pallet Dispensers, Bag Dump Stations, Bag Compactors, Drum/Box/Container Dumpers, Weigh Batching and Blending Systems, and Automated Plant-Wide Bulk Handling Systems – all to food, pharmaceutical or industrial standards.

Custom engineered systems incorporate equipment manufactured by Flexicon as well as packaging machines, blenders, weigh feeders, screeners and any other process and storage equipment required – all integrated with the process and guaranteed to perform.

Large-scale bulk handling systems are managed by Flexicon's Project Engineering Division that offers dedicated Project Managers as a customer's single point-of-contact, Engineering Teams that ensure smooth integration with new or existing systems, and the resources and effectiveness only a major bulk equipment manufacturer can provide.

Flexicon's worldwide testing facilities simulate full-size customer equipment and systems, verify performance prior to fabrication, demonstrate newly constructed equipment for visiting customers, and study the performance of new designs.

The company is currently doubling the size of its current

Flexicon offers stand-alone bulk handling equipment as well as plant-wide systems integrated with new or existing processes

90,000 ft² (8350 m²) manufacturing facility and world headquarters located in Bethlehem, PA, and also operates manufacturing facilities in Kent, UK; Queensland, Australia; and Port Elizabeth, South Africa. **www.flexicon.com**

Blending pasty products at high solids content

EKATO's VPT vertical blender is up to the task

EKATO SYSTEMS GmbH offers "made in Germany" technology for mixing pasty products with high solid contents.

Quick and effective blending of such products requires agitation systems with high torque. Both Z-kneaders and horizontal ribbon blenders are quite expensive and difficult to discharge completely.

The EKATO SYSTEMS VPT vertical process blender offers 25% less torque demand and a discharge of up to 98%, compared with horizontal drum blenders.

The VPT features a heavy-duty "top entry" agitator, combined with a baffle system designed for liquid and solids blending to reduce both operation costs and batch times. The high impeller efficiency reduces energy input into the blend and avoids an excessive temperature rise during the batch cycle. Benefits include:

- vertical system with lower investment and maintenance costs compared to horizontal systems;
- no product wetted seals mean longer life;
- GMP-compliant design available;
- fast liquid incorporation in bulk solids – 30% less batch time;
- high-yield discharge system for maximum yield of valuable product – up to 98%;
- commercially proven design;
- worldwide sales and service network.

Applications include:

- PVC in methylene chloride paste;
- aluminum/water paste;
- pigments in petroleum paste;
- graphite plus water/oil paste;
- cocoa powder/palm oil paste.

www.ekato.com

Transferring toxic substances?

The new-generation Müller Containment Valve aids safe handling of highly potent or toxic materials

Whether operated manually or automatically, the **Müller** Containment Valve MCV ensures that products transfer safely – from the intermediate bulk container into the process line and back into a container. After a successful start with their own split valve in 2009, Müller has now optimized the Containment Valve MCV to meet even higher requirements. The new valve generation is suitable for up to OEB Level 5 (SMEPAC), i.e. up to OEL <1 µg/m³. In addition to the higher OEB Level, the operator benefits from improvements in the valve's handling. The new construction is lightweight, compact and self-locking. The locking mechanism is smooth-running but powerful, with no rollers or bolts, so there is no mechanical wear. Changeover from a manual to a pneumatic version, or refitting position sensors, is simple and easy. Several versions are available, covering options including pressure rating up to 6 bar, explosion pressure shock resistance, and prevention of flame breakthrough for group IIB gases up to 10 bar (except valve size DN 250, which is "only" resistant up to 6 bar). All valves come in AISI 316L stainless steel, or Hastelloy if required. Available valve sizes are DN 100, DN 150, DN 200 and DN 250.

Müller Containment Valve MCV: now meeting even higher standards

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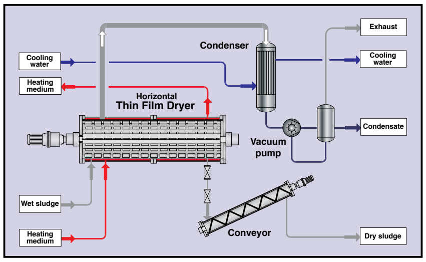
Dry biosolids at low temperature

The Buss-SMS-Canzler Thin Film Dryer saves energy in wastewater treatment, and can use waste heat too



The Buss-SMS-Canzler low-temperature biosolids drying process

Drying of biosolids – like sludge from municipal and industrial wastewater treatment plants – with **Buss-SMS-Canzler** Thin Film Dryers type NDS is a technology proven over more than 25 years in a huge number of installations. Drying typically takes place at atmospheric pressure and temperatures of 130–180°C.

To improve the environmental performance and economics of biosolids treatment, the trend is towards reducing energy consumption. One way to do this is to take advantage of low-temperature (80–130°C) waste heat that is often available from power plants or other parts of the process, for example.

To enable greater use of waste heat, biosolids can be dried under vacuum to reduce the necessary evaporation temperature.

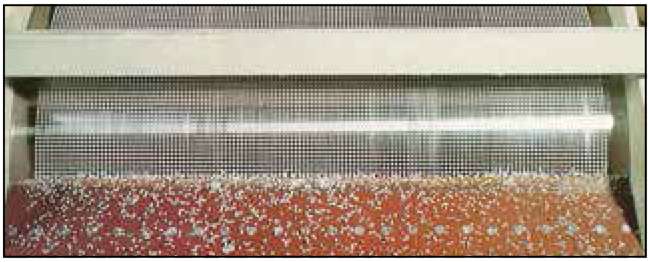
Tests have shown that low-temperature vacuum drying using a Buss-SMS-Canzler Thin Film Dryer works well for biosolids, with a plant layout very similar to that used for conventional atmospheric-pressure drying. The advantages are:

- lower overall thermal energy consumption;
- use of waste heat, if available, improves economics and cuts emissions;
- minimized hazard potential because the product temperature remains below 100°C – much lower than the ignition temperature of biosolids; and
- downstream cooling is in most cases not required, since the product outlet temperature is in the range 40–70°C.

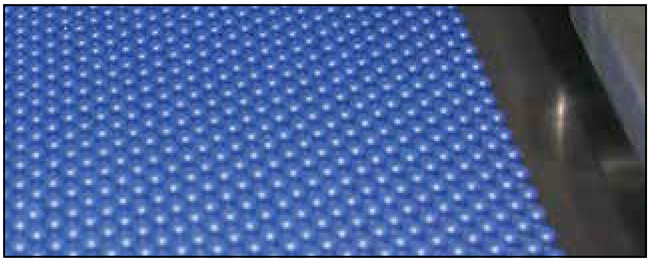
www.sms-vt.com

Steel belts for chemical processing

Berndorf Band supplies high-quality stainless steel belts used to cool and solidify chemicals and a variety of other applications



Carefully chosen material grades and manufacturing methods...



...yield high-quality products and long, trouble-free working life

Berndorf Band is a worldwide leader in top-quality process belts. The company uses selected grades of stainless steel and advanced manufacturing technologies to produce steel belts characterized by improved machine availability and long working life.

Endless steel belts can be used for various applications in chemical processing. These range from standard cooling applications, used to solidify chemicals, up to high-end applications such as film and foil casting on mirror-polished steel belts. Whatever the application, the use of an endless steel belt allows continuous production.

The company chooses its materials to resist the dynamic stresses created by continuous running and repeated bending over drums and rollers. The belts are characterized by their perfect flatness, dimensional stability, and straight tracking.

Berndorf Band offers state-of-the-art field service for all its products. A wide variety of service activities are offered, from emergency repair to preventive maintenance. The company's international service network is supported by the service centre in Berndorf, Austria. As a result, customers always have rapid access to the latest repair methods and skilled technicians. **www.berndorf-band.at**

Protecting Against Compressor Pulsations

Minimizing detrimental pulsation behavior by examining harmonics improves operations and safety

Ali Ghanbariannaeeni
Lloyd's Register EMEA

Ghazalehsadat Ghazanfarihashemi
AMEC Group Ltd.

Pressure variations resulting from the oscillatory flow patterns found in positive-displacement machinery, especially reciprocating compressors, are referred to as "pulsations." Found in both liquid- and gas-handling systems, pulsations are a common phenomenon in the chemical processing industries (CPI). Operational problems associated with pulsations include resonance conditions, high vibrations, degradation of support systems and increased risk for fatigue failures caused by dynamic forces. To avoid potential pulsation-related problems in reciprocating compressors and piping systems, there are two design considerations that must be taken into account. The first focuses on minimizing the magnitude of the harmonic forcing functions. The second method examines physical modifications to the piping support or piping layout to mitigate issues related to natural frequencies and harmonics. This article covers the first method in detail.

Excitation sources

In systems that employ positive-displacement machinery, the pressure and flow of the gas or liquid are not steady. Instead, the fluid moves through the piping at varied conditions in a series of pressure pulses. These variations are superimposed upon the steady (average) and dynamic regimes in Figure 1. In addition, flow pulses act as excitations that create pressure and flow modulations, namely acoustic waves, which propagate at a speed equal to the speed of sound through the process fluid as it moves through the piping system. The frequencies of flow pulses are a function of the mechanical properties of the compressor, including the compressor's piston-displacement and crank-rotation behavior. The piston-displacement function for reciprocating compressors is shown in Figure 2.

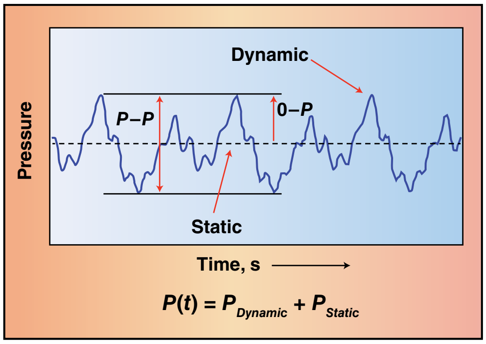


FIGURE 1. Pressure variations are shown for the inlet and outlet of a reciprocating compressor

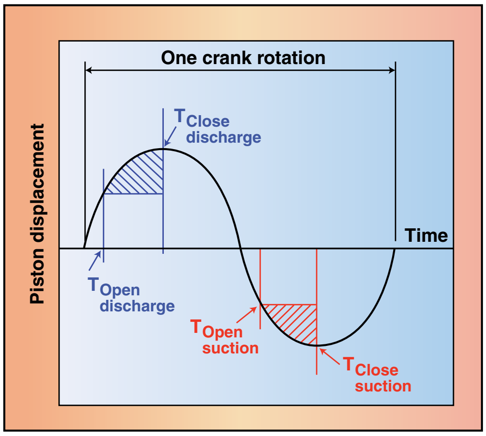


FIGURE 2. A compressor's piston-displacement function over one shaft rotation is shown. The piston-displacement characteristics of a compressor affect the flow-pulse frequency

Flow variations, as plotted in Figure 3, appear as a saw-tooth flow function at both the suction and discharge sides of the compressor cylinder. The shape of the saw-tooth is determined by the rotational speed of the compressor, the single- or double-acting features of the compressor, the geometry of the cylinder-cylinder valve and the pressure ratio.

Actually, studying the crankshaft of a compressor allows for some predictability of the pulsation-producing behavior. Pulsations are produced at a rate equivalent to the compressor-crankshaft displacement, in revolutions per minute (rpm), and multiples thereof. Pulsation frequencies are generally expressed in cycles per second, or Hertz (Hz). For example, a 600-rpm compressor produces pulsations at 10, 20 and 30 Hz, as well as higher multiples. Compressors in natural-gas services are mostly double-acting, and compress gas on the head and crank ends of the cylinder. Double-acting cylinders produce more pulsation at the even multiples of crankshaft speed and less at the odd multiples. Therefore, a 600-rpm double-acting cylinder will produce its strongest pulsation at 20 Hz. When compressors have more than one cylinder, the crankshaft phasing of the cylinders will also cause certain multiples to be higher than the others. For example, if two double-acting cylinders are phased 90 deg

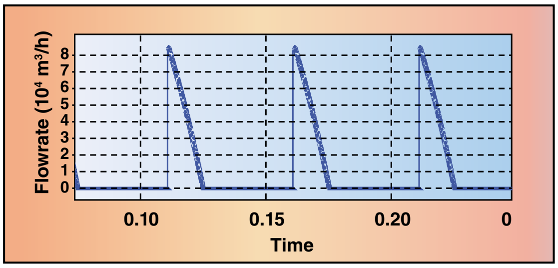


FIGURE 3. Flow variations at the inlet and outlet piping of a compressor take on the form of a saw-tooth function

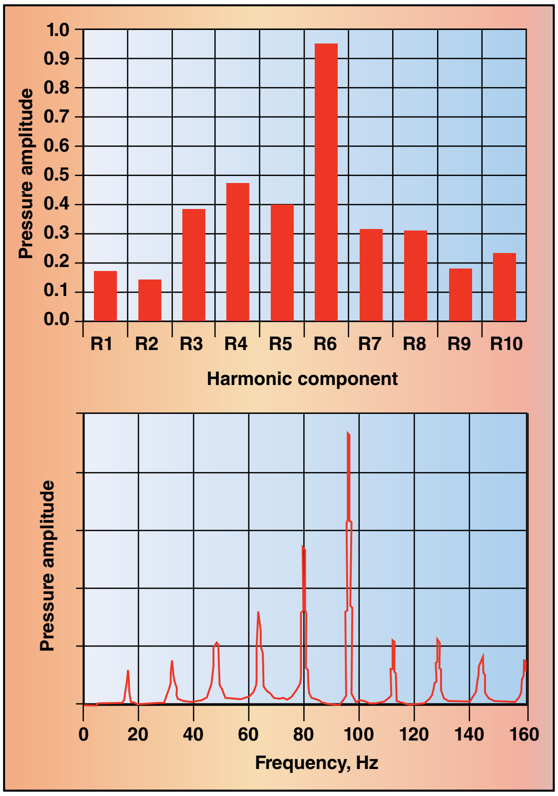


FIGURE 4. Fourier analyses of pressure and flow reveal the harmonic and frequency behavior for a compressor

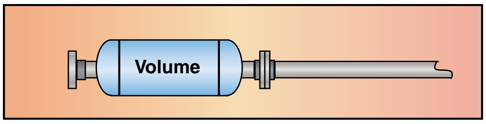


FIGURE 5. A typical single-volume dampener is available in two types, cylindrical or spherical

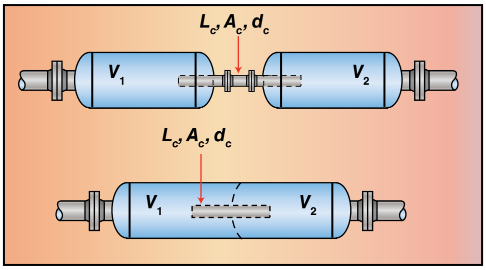


FIGURE 6. A double-volume pulsation dampener features two volume chambers that are connected with either an external (top) or internal (bottom) choke tube

apart, they will produce a significantly higher pulsation level at four times the crankshaft rpm level. In the case of a 600-rpm machine with two double-acting cylinders phased 90 deg apart, there will be a high fourth harmonic or 40 Hz. Generally, the higher multiples — sometimes called compressor harmonics or compressor orders — will contain less energy than the lower orders. When a discrete Fourier analysis is performed on the aforementioned saw-tooth function, the strength of the individual flow harmonics is determined. The discrete Fourier analysis of the flow's saw-tooth function indicates which harmonics of the compressor running speed produce the largest pressure amplitude, as seen in Figure 4.

In most pulsation analyses, the pressure amplitudes for the first to tenth harmonics are usually used in the acoustic model to predict the pulsations and unbalanced forces. Any pulsations must be smaller than the limits given in API 618 [*1*], which defines the minimum suction and discharge surge volumes required for pulsation control. Additionally, unbalanced forces must not produce a fatigue failure on the piping system. Typically, the predominant pressure and flow modulations generated by a reciprocating compressor are at frequencies that can be modeled as generalized one-dimensional waves. However, in high-speed reciprocating compressors, such as those with speeds between 750 and 1,000 rpm, this assumption is not correct and a three-dimensional analysis should be conducted on both compressor suction and discharge manifolds.

Pulsation control

Pulsation control in compressor piping systems can be accomplished by proper application of the basic filter elements, including pulsation dampeners, single- or double-volume bottles, choke tubes and orifices. These elements can be combined in various manners to achieve pulsation control ranging from attenuation of pulsations to true filtering.

Pulsation dampeners of any volume cause the dissipation of pulsative energy, preventing its transmission through a system. In most chemical plants, single-empty dampener volumes — usually spherical or cylindrical styles — are used. However, double-volume dampener filters with internal or external interconnection piping are also relatively common. The line between the two volume chambers in a two-volume dampener is referred to as the choke tube. Figures 5 and 6 illustrate single- and double-volume dampeners, respectively. The double-volume model is shown in both internal and external types, with choke-tube parameters as follows: choke-tube length (L_c), choke-tube area (A_c) and choke-tube internal diameter (d_c).

In general, suction pulsation dampeners are mounted directly at the top of the cylinders, and discharge dampeners directly at the bottom. In fact, the API 618 standard requires a top-to-bottom gas flow to allow for proper liquid drainage. To gain insight into the effectiveness of the various configurations, the pulsation transmission factor (*TF*) is used. This factor is defined in Equation (1), in terms of a pulsation amplitude ratio, where Q_{in} is the amplitude of pulsation at the dampener inlet and Q_{out} is the amplitude of pulsation at the dampener outlet.

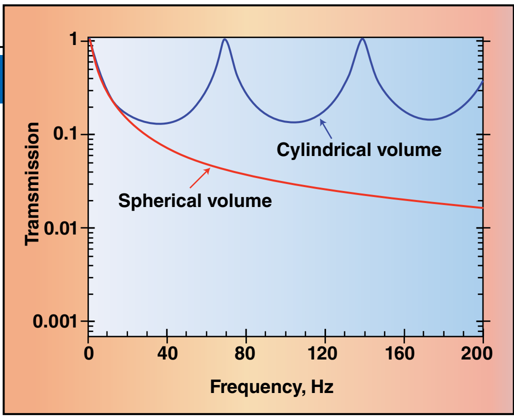


FIGURE 7. A comparison of the transmission characteristics of cylindrical and spherical dampeners reveals the excellent attenuation potential exhibited by the spherical type

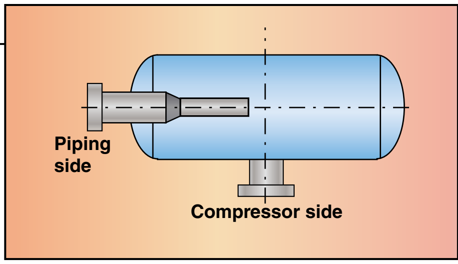


FIGURE 8. A pipe can be inserted directly into the cylinder to balance forces.

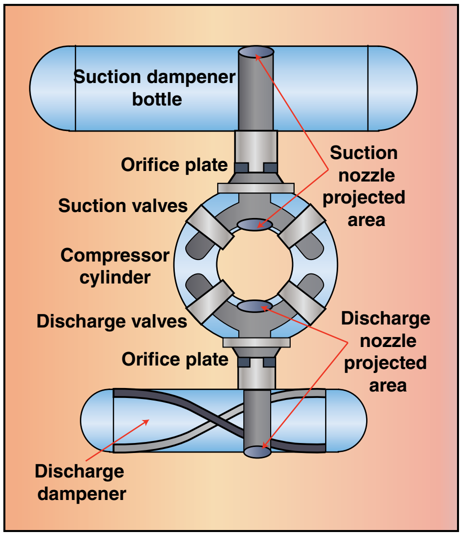


FIGURE 9. Orifice placement with respect to nozzles and flanges is crucial in pulsation control

$$TF = Q_{out}/Q_{in} \quad (1)$$

The frequency at which Q_{out} is equal to Q_{in} is called the passband frequency. This frequency indicates a maximum in pulsations and is registered as resonance in the dampener. Thus, it is desirable to decrease *TF* by changing the dampener dimensions and area ratio to minimize pulsation amplitude downstream. By comparing the transmission factor of each pulsation dampener with other types of dampeners, it is possible to gain knowledge of the strengths and weaknesses in each configuration. This matter is explained in more detail in the following sections.

Single-volume dampeners

A single-volume (empty bottle) dampener, in either a cylindrical or spherical style, is attached to the suction or discharge of a compressor. This volume provides surge capacity and acts as a filter, which can effectively isolate the piping fluid from the flow modulations induced by the compressor. Based on the standards set in API 618, the surge volume is defined as 21 times the combined swept volume of the head and crank end of the compressor cylinder, corrected by a square root function for the speed of sound difference between a typical natural gas with a speed of sound of 600 m/s. However, in most applications, assuming 30 times the piston sweeping volume is considered an acceptable preliminary estimation.

The *TF* value of this type of bottle is reduced with increasing volume and a decrease in the piping cross-sectional area. In other words, the attenuation characteristics of the empty volume are a function of the volume enclosed by the bottle, as well as the expansion ratio of the attached pipe and bottle diameters. Moreover, according to API 618, for a single-cylinder empty volume bottle, the ratio of bottle length to inside diameter (L/D) shall not exceed four. However, in most practices, an L/D of approximately three is considered acceptable, with a general assumption that bottle diameter should be three to four times the compressor nozzle diameter. Bottle length should be minimized when comparing acoustic length response with the compressor excitation frequencies; in this regard, dampener length should be selected to be less than one-fourth of the compressor's main harmonic wavelength. Also, passband frequencies are controlled by the bottle length, because they occur at half of the pulsation wavelength.

It is important to understand the differing characteristics of spherical and cylindrical dampeners. In general, a spherical single-volume type is much more efficient than the cylindrical type, but because of restrictions on fabrication costs, the cylindrical dampener type is much more commonly used. The transmission characteristics of spherical and cylindrical dampeners are illustrated in Figure 7. Here, it is seen that the cylindrical volume and the ideal volume are equal [*2*]. The spherical volume transmission indicates excellent attenuation characteristics, making it a very effective choice for pulsation dampening, if not for the high associated costs.

Practical recommendations

Compressor manufacturers should provide pulsation bottles for both the suction and the discharge side of each cylinder, and cylinders operating in parallel configurations can be connected to a common suction or a common discharge bottle, if possible, and in accordance with API 618 requirements. However, suction-pulsation bottles should be designed to prevent liquid trappage and should not be equipped with internals for moisture removal. As such, suction piping is sloped back toward the knockout drum to prevent liquid accumulation in the machine suction bottles. Similarly, discharge bottles must be self-draining. Moreover, if suction bottles and piping are provided by the compressor vendor, they must have attachment features or facilities for installing insulation and heat tracing to maintain the metal temperature at least 6°C above the rated gas temperature for the suction. It is recommended that welding-neck flange types be used in bottle fabrication, except for inspection or cleaning flanges, and that long-welding-neck type (LWN) flanges be used for instrument devices. All welds in bottle construction should be full-radiography afterwards; the root pass of welding should be gas-tungsten arc welding (GTAW) type and the next passes should be shielded-metal arc welding (SMAW) type [*3*].

Suction dampener supporting

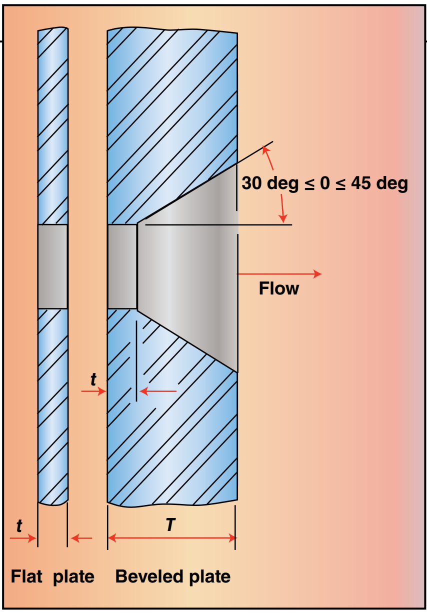


FIGURE 10. Orifice plates are an integral part of pulsation control and must be installed with consideration to flow direction

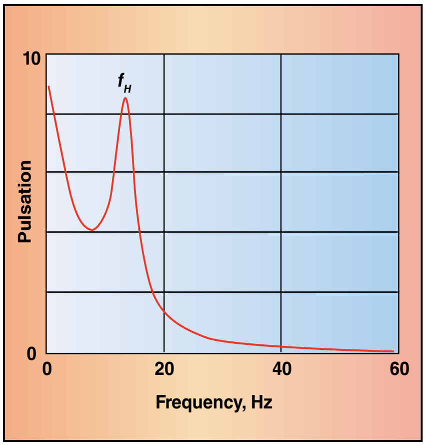


FIGURE 11. A volume-choke-volume dampener configuration results in a frequency response (f_H) where pulsations are amplified, and then drop off rapidly

should be installed in a goalpost-type arrangement, and not on the compressor cylinder itself. It is recommended that tapping on the shell be minimized and pressure and temperature indicators be installed on the main nozzles or piping manifolds. One of the best practices for the design of volume bottles is to place the cylinder connections at the longitudinal center of both the suction and discharge bottles. In fact, the cylinder nozzle exit in the discharge bottle, or entrance, in the case of the suction side, can be the origin of the pressure pulsations in the bottle itself. If this origin is placed symmetrically with respect to the bottle ends, the pressure pulsations will hit the two opposite sides with the same phase, resulting in zero net pulsations.

In addition, the length of cylinder nozzle connections must be limited, because longer nozzle lengths result in more harmonic resonance in the section of pipe between the cylinder and the volume bottle. However, there is an exception with very light gases, such as pure hydrogen or helium, because high gas-sound velocity and wavelength produce no resonance in short lengths of pipe. In this case, the minimum bottle acoustical natural frequency that could be excited in resonance is above the tenth harmonic.

Due to restrictions on machine component layouts, including cylinder arrangement, interstitial spaces between cylinders or supporting structures for the bottles, there are some cylinders for which reaching the center of the cylinder is not possible from outside of the volume bottle. In these cases, a standard design practice is to insert a section of pipe directly into the bottle to balance the volume-bottle cylinder's connection to the center of the volume bottle (Figure 8).

Another best practice is positioning a fixed orifice plate in the cylinder flanges. Actually, as illustrated in Figure 9, the standing wave pattern of the pressure pulsation is carried from the valves through the cylinder gas passages and the cylinder nozzle into the bottle, on each side of the cylinder. This pressure pulsation acts to produce varying positive and negative forces in the vertical direction. Dampening of this resonance is necessary to avoid excessive shaking forces inside the bottles and to prevent damage to the cylinder valves on the other side [*4*].

As a result, orifice plates in the throat of the flanged inlet or outlet nozzle connections are mandatory to reduce the pulsation amplitude, called nozzle-mode frequency, which is present between the cylinders and the volume bottles. These orifices must be located exactly at the outlet flange for the suction volume bottle and at the inlet flange for the discharge volume bottle. Orifice installation between cylinder flanges and pulsation dampener flanges has an advantage. When needed, the orifice plate can be easily changed during a plant overhaul or a redesign for new operating conditions. Furthermore, orifices in outlet connections for discharge bottles and in inlet connections for suction bottles can change piping cross-sectional area, increase *TF* and subsequently decrease the pulsation level prior to the dampener on both the suction and discharge sides.

The orifices' recommended pressure drop is a maximum of 1% of the line's mean pressure. They are typically large-bore orifice plates, and can provide equivalent pressure drop in the order of a valve or approximately 1/100 the diameter of the pipe. The normal orifice discharge coefficient (C_d) is 0.6, but orifices lose their efficiency at higher frequencies and in these cases, the user might consider multiple-bore orifice plates [*5*]. The preferred material is stainless-steel type AISI 304 or 316 with 10-mm thickness. Most orifices have a clearly marked flow direction and should be installed carefully. The flow direction is always from the small-opening end to the large-opening end (Figure 10).

Double-volume dampeners

Two-volume dampeners are an extension of the single-volume variety, and there are significant differences in these two types of dampeners, with regard to low-frequency characteristics. The first bottle, which is directly connected to the compressor cylinder, is called the surge volume and the second bottle is the filter volume. Recall that a choke tube separates the two volume chambers in a double-volume dampener, hence the volume-choke-volume label. The single most important characteristic of a dampener's volume-choke-volume configuration is its acoustic natural frequency — or Helmholtz frequency. This is a value at which a frequency pulsation is amplified, followed by a rapid drop-off in pulsation levels (Figure 11). Equations (2) and (3) are used to calculate

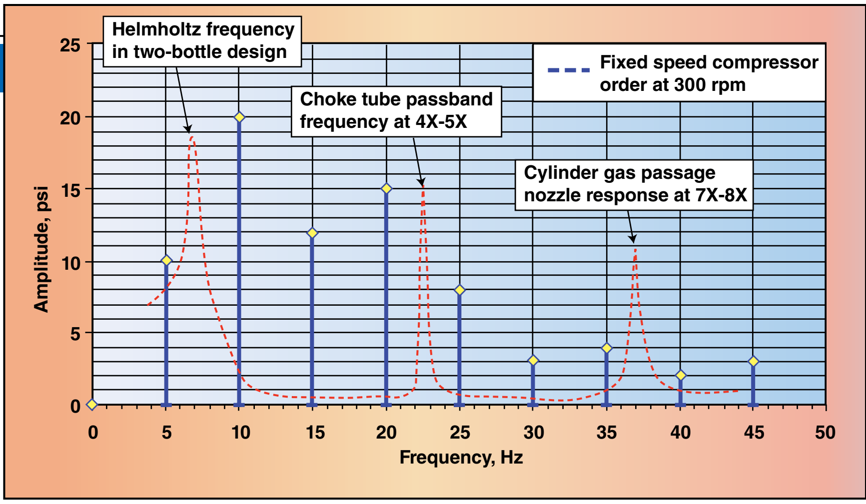


FIGURE 12. A volume-choke-volume system's frequency response is plotted with passbands for a 300-rpm reciprocating compressor

the Helmholtz frequency (f_H) [6] in terms of the speed-of-sound propagation through the process gas (C). L'_c represents the corrected choke-tube length.

$$f_H = \frac{C}{2\pi}\sqrt{\frac{A_c}{L'_c}\left(\frac{1}{V_1}+\frac{1}{V_2}\right)} \quad (2)$$

$$L'_c = L_c + 0.6d_c \quad (3)$$

Figure 12 shows the realized response of double-volume dampeners, superimposed on the pulsation spectrum for a 300-rpm double-acting compressor. This figure exhibits a relatively high Helmholtz frequency compared to choke-tube passband and nozzle-mode response frequencies. The passbands, which amplify certain frequencies, are related to design considerations, such as the length of choke tubes and inlet nozzles. The frequency of passbands must be carefully considered to ensure low dynamic-pressure transmission and good compressor isolation. Actually, passband frequencies are controlled with dampening by adding pressure drop (orifices) or flow losses (choke tubes). However, adding dampening reduces compressor performance and increases power losses and operating costs. The minimum surge volume requirements and dampening are controlled by pressure drop in the choke tube. At frequencies below the Helmholtz frequency, there will be no attenuation of pulsations passing through the dampener.

Meanwhile, there will be a sharp reduction of pulsation at about 20–40% above the Helmholtz frequency and extending out to several Hertz before the passband frequency, due to choke-tube and cylinder-gas passage. In addition, it is very important to account for margins between the compressor pulsation and the Helmholtz frequency. This margin can be evaluated in two ways. For speeds above 500 rpm, the Helmholtz frequency should be placed 30% below the compressor pulsation (or rpm divided by 60). On the other hand, for compressor speeds below 500 rpm, the Helmholtz frequency should be placed 33% above the compressor pulsation. This 33% margin can also be applied in other cases, due to economical restrictions, physical impracticality, or when pressure drop is very critical in low suction pressures or when there is limitation in space for the compressor layout.

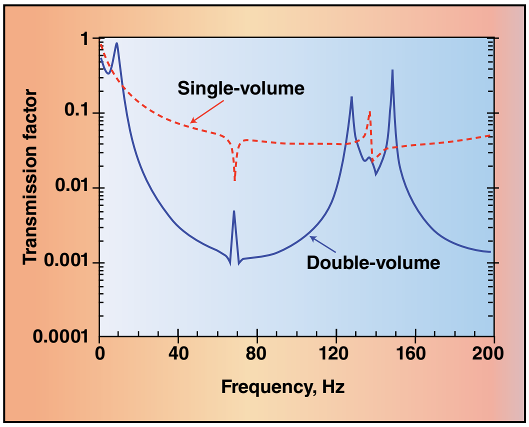


FIGURE 13. A comparsion of single- and double-volume dampeners shows that double-volume dampeners provide attenuation over a wider range of frequencies

Double-volume dampeners can be used effectively to control pulsation with relatively high molecular-weight components and relatively low-speed systems with velocities less than 600 m/s. Each bottle volume (surge and filter) is approximately sized to be ten times the piston sweeping volume. The preferred arrangement is symmetric, with equal length between the bottles and the choke tube. It is worth noting that in symmetrical dampeners, passband frequencies are minimized. Besides this, the inside diameter of the choke tube should be so small that pressure-drop limits are minimized. Larger-diameter choke tubes create less pressure loss but require larger volumes. In most applications, a common procedure is to limit the gas velocity to 30 m/s for initial choke-tube sizing.

Double-volume dampeners with internal choke tubes and baffle plates are generally appropriate for speeds lower than 500 rpm and lighter gases. Conversely, dampeners with external choke tubes are generally appropriate for speeds higher than 500 rpm and heavier gases. The bottles' diameter should be three to four times the compressor nozzle and outlet piping diameter. Bottle length will depend on the acoustic design technique. With regard to nozzle frequencies, dampening is controlled by the pressure drop in the nozzle, with the ideal location for pressure drop being the bottle's connection. Design considerations for controlling the main amplified frequencies are summarized in Table 1.

Comparison of dampeners

The selection of a pulsation dampener depends on compressor speed, compressor construction, gas thermodynamic properties, sound velocity and the degree of pulsation control required. Figure 13 compares single-volume and double-volume dampener performance in terms of the transmission factor. The empty single-volume dampener provides adequate attenuation of pulsations between frequencies of 0 and 10 Hz.

TABLE 1. CONTROLLING AMPLIFIED PULSATION FREQUENCIES		
Helmholtz resonance	**Choke tube passbands**	**Nozzle-mode response**
Volume of 1st chamber Volume of 2nd chamber Length of choke tube Area of choke tube	Length of choke tube Chamber length (if not center-fed by nozzle) Choke tube pressure drop	Cylinder passage volume Effective cylinder length Length of nozzle Volume of first chamber

After that, the two-volume dampener has superior attenuation characteristics in the 10–120 Hz spectrum. In other words, for maximum attenuation over a wider frequency range, two-volume dampeners may be a more appropriate option. However, in two-volume pulsation dampeners, the transmission factor strongly depends on compressor gas composition and speed, whereas single-volume dampeners exhibit steady behavior under a variety of operating conditions — a single-volume dampener experiences very little efficiency decrease in a dynamic environment.

Actually, experience has shown that a single-volume dampener is effective and the preferred solution in pulsation dampening in most CPI plants. Moreover, pressure drop is lowest in this type, and there is much lower possibility for mechanical problems or failure of internals.

Conversely, in double-volume dampeners, internal component failure is a major weakness. Overall, operations are simpler and more flexible with single-volume dampeners. For example, double-volume dampeners must be synchronized according to the specified compressor operation; this process is not necessary for single-volume dampeners. For double-volume configurations, significant changes in operating conditions or gas composition may require the replacement of the volume bottles and internals, but pulsation control in single-volume dampeners can be adjusted by insertion of removable orifices or by additional volume located close to the existing bottle. Finally, due to the need for bottle internals in a two-bottle design, the cost of these devices is normally higher than that of a single empty-volume system.

Correct design of pulsation devices is an important step in ensuring safe and reliable operations by mitigating vibrations of compressors and piping-manifold systems. Usually, when designers adhere to the initial sizing procedures for pulsation dampeners, a final acoustic and vibration study will indicate the need for only minor equipment modifications, such as adding orifices or changing the support-piping type or layout. ■

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Integrally Geared Compressors in the CPI

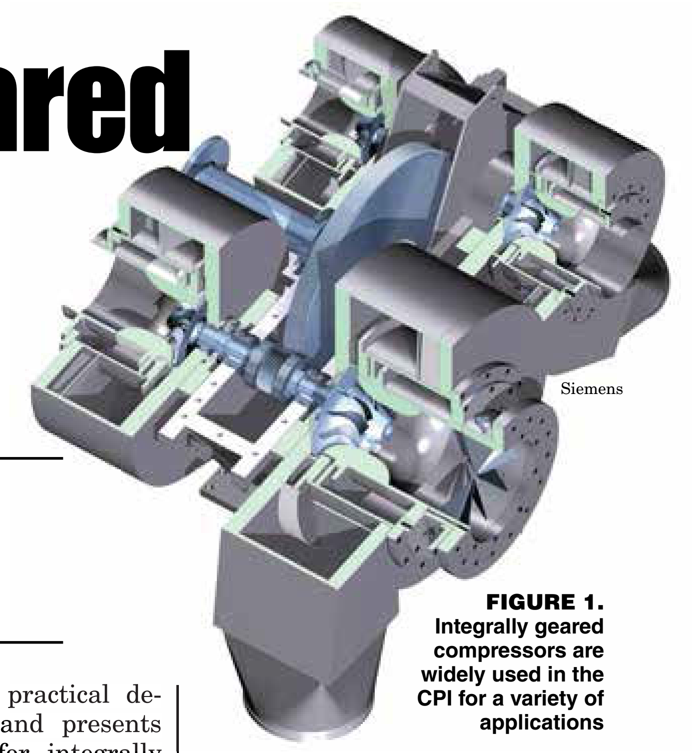

FIGURE 1. Integrally geared compressors are widely used in the CPI for a variety of applications

Follow this guidance to improve operation, safety and reliability of integrally geared compressors

Amin Almasi
Rotating Equipment Consultant

In an integrally geared centrifugal compressor (Figure 1), several impellers are mounted on the ends of high-speed pinion shafts, which are rotated by a bull-gear. Each impeller's casing is mounted directly on the horizontally split gear casing. As is the case for any turbomachinery type used in the chemical processing industries (CPI), there are advantages and disadvantages associated with the use of integrally geared centrifugal compressors. When compared to conventional centrifugal compressors, integrally geared compressors are more compact and generally less expensive. Also, an integrally geared centrifugal compressor can offer higher efficiency compared to conventional compressors, mainly due to improved intermediate cooling capabilities and the optimization of impeller speed at the final impellers, where the gas volume has been reduced after encountering the initial impellers. Also, since the compressor stages use independent three-dimensional (3D) impellers, there are more opportunities for intermediate cooling.

On the other hand, integrally geared compressors are quite complex, potentially leading to dynamic and reliability issues. This article details some practical design considerations and presents some process data for integrally geared compressors.

Design and operation

In an integrally geared centrifugal compressor, a two-part gear casing permits the gears and bearings to be readily checked without removing the compressor casings. This casing has its upper and lower halves joined at their horizontal flanges. Each individual compressor stage has a vertically split casing design. The pinion shafts each rotate at a high speed, enabling the impellers fitted on each end to efficiently compress the gas. The pinion-shaft assembly is removable, providing easy access for maintenance. The high-speed rotor design should be tuned based on both lateral and torsional dynamic results.

In the CPI, tandem dry-gas seals are commonly used in integrally geared compressors, which require longer pinion rotors, making rotordynamic issues more complex. For the high-speed rotors in integrally geared compressors, tilted-pad journal bearings, either with or without a squeeze film damper, are most often used. Investigations show that the machines equipped with squeeze film dampers usually perform better than the ones with only the tilting-pad journal bearing.

The rotor design is the most important factor in securing mechanical stability against destabilizing fluid forces. Destabilizing forces usually increase as the actual discharge pressure increases. For high-pressure stages, for instance those above 70 bars, the stability of the rotor, including the pinion, two impellers and seals, should be ensured. There are usually concerns about high-speed shaft vibrations and the temperature of the bearing pad. Particularly important in the design phase are the vibrations of the rotor and the temperature rise in the high-speed bearing pads. These phenomena should also be confirmed in compressor performance tests. Generally, the temperature in the high-speed bearing pads should be less than 100°C. However, in actual operations, the observed temperature for the entire journal bearing pad is often lower than 70°C.

The shafting in the two impellers is nearly symmetrical, resulting in a relatively balanced aerodynamic thrust. Thrust loads from impellers and gears should be absorbed by individual thrust bearings on pinions, or transmitted to the bull-gear thrust bearing by means of thrust-rider rings fixed to the pinions and

TABLE 1: EXAMPLE CAPACITY RANGE FOR A FIVE-FRAME INTEGRALLY GEARED COMPRESSOR	
Compressor frame	Capacity range (m^3/h)
1	1,000–4,000
2	4,000–20,000
3	20,000–50,000
4	50,000–110,000
5	110,000–300,000

TABLE 2: EXAMPLE POWER CAPABILITIES OF A NINE-FRAME INTEGRALLY GEARED COMPRESSOR	
Compressor frame	Power range (MW)
1	2–4.5
2, 3, 4, 5, 6	5–25
7, 8, 9	25–65

bull-gear. The latter approach is commonly used in integrally geared centrifugal compressors. In many machines, a large degree of thrust balancing may be achieved by the helix thrust-force direction of the gearing, which offsets impeller aerodynamic thrust forces. Integrally geared compressors are typically fixed to the mounting plate and, if avoidable, should not be moved for alignment — this can cause distortion of the integral gear unit.

Integrally geared centrifugal compressors are offered with different frames, and are available in a wide range of sizes for many applications. As a very rough indication, each frame is around 50–120% bigger than the previous frame. Tables 1 and 2 show some typical frame schemes for integrally geared compressors, illustrating capacity range and power range, respectively.

Lubrication oil systems

The lubrication oil system in integrally geared compressors is critical for operations, and proper design is key in minimizing potential issues. For small- and medium-sized compressors, the lubrication oil system is usually part of the compressor package. Often, the integral gear casing (the main casing) has a hole in its bottom, through which the return oil travels directly down to the lubrication oil reservoir. This reservoir is a wide, low-depth reservoir integrated within the common baseplate. The primary oil pump is often driven by the main equipment shaft in a direct-coupling arrangement or through a gear system. This connection or gear system needs special attention, since in some machines, these components can potentially cause operational difficulties. The lubrication oil pump and its gear connection should be provided according to American Petroleum Institute (API; Washington, D.C.; www.api.gov) standards, specifically the requirements specified for gear systems in chapter three of API-617. The lubrication oil itself can also be the source of problems, especially due to the high sensitivity of integrally geared compressors.

Generally, centrifugal compressors are sensitive to operating condition irregularities — this includes changes in gas composition or lubrication oil temperature. For example, in a given integrally geared compressor in a CPI plant, a 15% increase in compressed-gas density resulted in 14% more destabilizing forces at the same compressor discharge pressure. In another example, an integrally geared compressor was designed to operate at a lubrication oil supply temperature of 43°C; there were no issues or rotor instability when operating at this lubrication oil temperature. However, during a short period of time, because of a problem in the lubrication oil skid, the oil supply temperature was raised by 10°C, causing an asynchronous vibration in the compressor. Generally, investigations have shown that integrally geared compressors are affected by any deviation in lubrication-oil temperature, whether it involves the temperature decreasing or increasing. Usually, for large and operation-critical integrally geared centrifugal compressor packages, a sophisticated lubrication oil system should be provided, designed according to chapter two of API-614. A robust and properly designed temperature-control system is crucial to the lubrication oil system.

Additionally, excessive oil temperature can sometimes be caused by lubrication oil foaming. The gear casing should be designed to permit rapid drainage of lubrication oil to minimize oil foaming. Proper attention should be given to the design of certain components, including windage baffles, false bottoms, sump depth and drain connections. Removable and gasketed inspection covers should be provided in the gear casing to permit direct visual inspection of the full-face width of all pinions and the bull-gear. For some compact machines, this design may not be possible, but the inspection opening should be provided at least for one-half the width of the gear face.

Other considerations must also be taken into account in the design of the lubrication oil system of an integrally geared compressor. Where practical, gear casings should be designed with internal oil passages to minimize external piping, as external piping that supplies lubrication oil to the gear casing usually decreases the reliability of the machine. The design of internal piping and tubing should also provide proper support and protection to prevent damage from vibration, as well as damage sustained from shipment, operation and maintenance activities.

The commonly used lubrication oils for integrally geared compressors are ISO VG 32 oils. In some cases, ISO VG 46 oils might be used, especially in sites with relatively hot ambient temperatures or relatively high-temperature operations. Oils with extreme-pressure additives may be used for some gear units, but these oils should not be used for integrally geared compressors.

Side-stream applications

Integrally geared compressors are commonly used in applications where space or budget are limited. Their low weight and compact design make them a popular choice for many functions. For instance, facilities with marginal power availability may use these machines because of their efficiency. An important application field for integrally geared compressors is services requiring side-loads or side-streams.

Compressors with side-streams (also known as side-loads) have been extensively used in some CPI plants due to the potential for optimization with these machines. Examples of compressor systems with side-loads include some process refrigeration systems, as well as process units where a recycled stream is cycled back to a reactor. Conventional compressors with side-streams have complex aerodynamic issues and complicated operational behavior. The mixing of flows inside conventional compressors can be difficult and problematic. However, integrally geared compressors can manage side-loads and side-streams without the same issues as conventional compressors.

Capacity control via an IGV

In order to enable operation at partial loads with reasonable efficiency, an inlet guide vane (IGV) system is used in an integrally geared centrifugal compressor. Essentially, an IGV system provides safe capacity control. With an IGV system in place, the flowrate can usually be reduced with an approximately constant discharge pressure. Depending on IGV and compressor details, the minimum flowrate could be between 50 and 70% of the rated flow. Commonly used designs of integrally geared centrifugal compressors can offer 60–100% capacity control with an automatic IGV at the first stage.

The inlet guide vanes should be located as closely as possible to the eye of the impeller. According to API-617, a cantilevered vane design is preferred, rather than a center-supported vane design. The control logics and failure options are also important with IGV systems. The IGV system should be designed such that the vanes tend to open on loss of the control signal.

Use of IGV systems can introduce some issues, though, of which engineers should be aware. The rotating impeller induces flow motion interactions that can affect the IGVs, the impellers' volute and the compressor piping. These interactions induce turbulent, unsteady flow patterns throughout the compressor package. The distortion patterns in front of an impeller appear to be different from the distortion measured at the exit of the impeller, where flow disruptions due to the volute are dominant. However, detailed investigations show that the flow fields in the front of the impeller are defined by both upstream and downstream components.

Simulations and investigations show that significant aerodynamic activities and complex flow patterns exist near the surface of an IGV. These activities and complex flow patterns indicate strong reactions between the IGVs and the inlet flow. Generally, the IGVs have two main effects on the inlet flow. The first effect is the pre-swirl, which is the predominant effect at small IGV angles. The second effect is the flow-restriction effect, which is active at moderate and large IGV angles (in addition to the pre-swirl). Where there is a moderate or large IGV angle, the IGVs reduce the inlet flow area and speed up the axial flows to the 3D impeller.

IGV placement and orientation is also an important factor. The IGV angle range can often extend from –25 to 75 deg. With a moderate IGV angle, the turning of the IGV (the pre-swirl effect) and the accelerating axial flow (the flow-restriction effect) generate thicker boundary layers at the IGV surfaces. With a large IGV angle, these effects can be intensified and flow separations could occur near the IGV surface. As the IGV separates the flow field into different compartments, the flow fields inside these compartments subsequently display their own patterns that could be comparatively independent of each other.

Another feature of IGV-induced flow patterns is the formation of wakes after the IGVs. The wakes can usually be divided into two types. The first type consists of the wakes generated by the finite thickness of the IGV. The second type is made up of wakes generated by the setting angle of the IGV. The former is most noticeable at small IGV angles. The latter is observable in moderate or large IGV angles.

The most significant fluctuations are usually caused by impeller rotation. The unsteadiness induced by the impeller exists in all upstream and downstream components. The sizes of these periodic waves are usually the same scale as the size of the impeller's blade pitch. The intensity of the waves can be related to the IGV setting.

For integrally geared centrifugal compressors, oftentimes, all fluctuations of field quantities in all directions are approximately of the same order of magnitude, most likely due to the impeller. Other contributors are the structure of each stage and the complex piping network between the different stages and inter-stage coolers, which propagate the fluctuations in 3D patterns. The intensities of these fluctuations are inversely proportional to the distance from the rotating impeller.

Simulations and field investigations have confirmed that a periodic wave pattern is present near impeller inlets. The number of waves is usually the same as the number of impeller blades. Once again, these waves' sizes are related to the impeller blade pitch. To avoid the possibility of resonance, the number of IGVs is chosen so that there is no common divisor of the numbers of the impeller blades, crossover vanes and diffuser vanes. For example, in an integrally geared compressor, seven IGVs and 17 impeller blades prevent the exact match of blade pitches.

IGVs can introduce a variety of reliability and operational problems, if not properly installed or designed. IGVs oscillate due to the unsteadiness of the flow field inside a compressor stage. The force and torque on the IGV system require special attention. Robust design and proper manufacturing can help to mitigate some intrinsic problems with IGVs, including fewer oscillations and increased reliability.

TABLE 3. PROCESS DESIGN DATA FOR SEVEN-STAGE INTEGRALLY GEARED COMPRESSOR

	Impeller diameter (mm)	Speed (rpm)	Pressure ratio	Discharge temperature (°C)	Flow (m^3/h)	Required power (MW)
First stage	760	7,600	1.89	118	55,000	1.46
Second stage	800	7,600	1.93	130	29,900	1.50
Third stage	410	14,700	1.94	130	15,800	1.50
Fourth stage	410	14,700	1.95	130	7,780	1.50
Fifth stage	220	23,900	1.72	115	3,990	1.19
Sixth stage	220	23,900	1.72	115	2,295	1.19
Seventh stage	130	42,100	1.72	115	1,331	1.19

The dynamic forces on IGV components are mainly composed of two components induced by pressure and viscosity. The asymmetric flow patterns in the system normally have the same frequency as the impeller rotation. Fluctuations at lower frequencies are usually induced by the IGV system. IGV angle is also a factor. The effects are weak for small IGV angles and are stronger for moderate and large IGV angles. The twisted shape of an IGV impacts the inlet flow field and causes unsteadiness in the flow, at the same time applying more dynamic forces on the IGV system. The force and torque on the IGV respond to the impeller-rotating frequency rather than the blade passing frequency. The low-frequency oscillations inside the flow field are induced by the IGVs.

Other reliability issues related to the IGV system involve failures due to material deterioration, such as corrosion or erosion. An excessive liquid carryover from interstage coolers and improper material selection for IGV components are also significant issues that could result in IGV failure. The materials of all critical parts, especially IGV components, should be carefully selected with respect to the worst possible design conditions. In a case study, a failed IGV resulted in a severe surge that caused major damage to the machine.

Package piping

A sophisticated piping design is required for an integrally geared compressor package, because the flow must be routed from the discharge of each impeller to the next stage, usually through an intercooler arrangement. The flow inlet to each impeller should be axial. An elbow, as well as a straight run of pipe, should be provided at the suction of each impeller. As a very rough indication, the straight run should be six times the suction diameter. A straightener can be used in a very compact layout to reduce the required axial distance. When the elbow forces the flow into a turn, changing from vertical to horizontal, the flow will be distorted. When the flow leaves the elbow, the tangential velocity forms two counter-rotating vortices. These vortices also generate fluctuations inside the compressor stage. Also because of these vortices, the pressure distribution on IGV surfaces can result in complex flow patterns. In other words, the distortion induced by the elbow can be coupled with pre-swirling, as well as the inherent distortions induced by IGVs and impellers, resulting in convoluted aerodynamic patterns and complicated excitations.

This aerodynamic unsteadiness propagates to the flow field upstream of the impellers at the suction piping of the stage. This unsteadiness is also present upstream and downstream of the compressor stage. In fact, the entirety of the compressor piping system will experience the dynamic effects of the impellers and IGVs. Furthermore, the flow field's fluctuation is affected by the package piping, especially the elbows, which direct piping from different stages to intercoolers and vice versa.

Nozzles are another important component in the piping package. API-617 defines allowable nozzle loads for integrally geared compressors, which generally are lower than the requirements for conventional compressors. In most cases, the allowable nozzle load is the maximum load that can be achieved while requiring expansion joints at large nozzles. This is particularly important for processing applications where the operating temperature differs greatly from the ambient temperature.

Vibration and reliability

Since the API-617 vibration limit is a function of speed, the vibration limit can be relatively low for high-speed pinion shafts, making vibration monitoring an important part of the compressor package. For example, for shafts operating at 30,000, 40,000 or 60,000 rpm, the displacement vibration limits would be around 16, 14 and 12 µm, respectively. In a shop or site performance test, the expectation is that the vibration appears at shaft rotational speed with an amplitude well below the vibration limit and with no significant asynchronous vibration. An asynchronous vibration is characteristic of rotor destabilization or an issue in the compressor gear systems.

Vibration monitoring is key for an integrally geared centrifugal compressor, particularly for its high-speed pinion shafts, low-speed bull-gear, gear systems and the driver. Generally, dual vibration measurements (usually oriented at ±45 deg) on each bearing of the pinion shafts and the bull-gear shaft should be installed. In addition, accelerometers and velocity meters should be installed on the main casing. Some relevant frequencies that should be monitored are as follows:

- Shaft running speeds
- Shaft running speed harmonics
- Gear-mesh speed
- IGV pass frequencies
- Vane pass frequencies
- Blade pass frequencies
- Harmonics of IGV, vane and blade pass frequencies
- Frequencies related to bearing issues and gear-system faults

As an example, for a given a four-stage integrally geared compressor driven by a 1,785-rpm electric motor, the first pinion speed (first and second stages) and the second pinion speed (third and fourth stages) were around 14,700 and 21,900 rpm, respectively. The gear-mesh speed was around 749,000 rpm and the vane passing speed was around 363,000 rpm. All of these speeds and frequencies, along with their harmonics, were monitored in the equipment's vibration-analysis scheme.

Putting it all together

The previous sections of this article covered some design considerations and practical recommendations for integrally geared compressors. Now, this information is illustrated in the following example, involving a process-type, seven-stage integrally geared centrifugal compressor in a CPI plant. The given compressor provided a pressure ratio of around 70. The average pressure ratio of each stage would be the seventh root of 70, approximately 1.83. Table 3 shows the process and design data for this machine. It can be seen that the pressure ratios of the four initial stages (1.89, 1.93, 1.94 and 1.95) were greater than the average value of 1.83, while the pressure ratios of three last stages (1.72) were smaller than the average value. The average estimated efficiency was around 77% for all stages. The machine used an automatic IGV on the first stage, providing capacity control in a range of 65–104% of the rated capacity. The estimated power for the compressor was around 9.53 MW. The estimated driver power was 11 MW.

With this article, engineers should have the information they need to understand the design and operation of integrally geared compressors. ■

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Engineering Practice

Principles of P&ID Development

The tips provided here will streamline efforts to develop piping & instrumentation diagrams

Mohammad Toghraei
Consultant

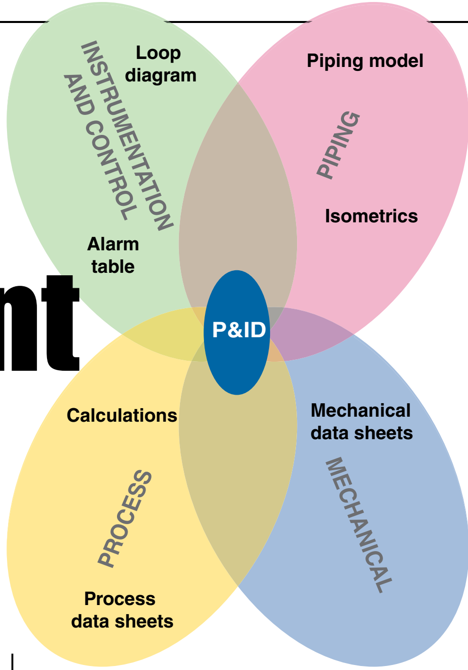


FIGURE 1. P&IDs are technically piping and instrumentation diagrams but they provide a central repository of essential engineering information that is relevant to numerous other functions throughout the planning and operation of most process plants

The piping and instrumentation diagram (P&ID) is often considered to be the gold standard for the proper design, operation and maintenance of plants in the chemical process industries (CPI), including chemical, oil-and-gas facilities, mining operations, food-processing plants, and water- and wastewater-treatment plants. The P&ID provides important information for manufacturing and installing equipment and machinery, piping, instrumention, and safe and appropriate startup and correct operation of the plant.

The P&ID is frequently referenced by various engineering disciplines — during both the design stages and the operating phase. It is also referenced in technical meetings with equipment vendors and manufacturers, in hazard and operability (HAZOP) studies, in management meetings, and during project scheduling and planning.

The P&ID is one of the few plant documents that is created by multiple engineering disciplines working in concert. These disciplines include process engineering, instrumentation and control (I&C), plot plant and piping (PL&P), mechanical, heat ventilation and air conditioning (HVAC), and to a lesser extent civil, structural and architecture (CSA), and the environmental and regulatory group.

Similarly, the information provided by the P&ID allows for the generation of various other important documents, including isometric drawings and models for piping, instrument lists, cause-and-effect diagrams, control philosophy, description, alarm-setpoint tables, line-designation tables (LDT), plot plans, loop diagrams, tie-in lists, and many more (Figure 1). With such universal applicability, P&IDs are often affectionately referred to as "primary interdisciplinary documents."

Role of the process engineer

The duties of the process or chemical engineer in a CPI project can be broadly split into two categories — equipment sizing and P&ID development. Therefore, most engineers need to have skills in both areas.

The former skill calls for knowledge related to hydraulic calculations, pump and compressor sizing, vessel and tank sizing, process safety-valve (PSV) sizing, and heat-exchanger sizing. Equipment sizing requires different skill sets, which may vary by level of seniority and by industry segment.

Chemical engineers should have the knowledge that is needed to size specific equipment components related to their industry segment (for instance, distillation towers for petroleum refineries and clarifiers for water treatment). While equipment-sizing skills are routinely taught during the acquisition of an engineering degree, the skills needed to develop meaningful P&IDs are often not formally taught in school, but rather are acquired through "on the job" training.

The absence of P&ID-development training in academia may result in part from the fact that inherently, P&ID development involves more art than science. Plus, the content and structure of individual P&IDs tends to vary from company to company, and there is a constant stream of new technologies being introduced as older ones are retired. While volumes could be written on the development of P&IDs, this article provides a framework of recommendations for P&ID development.

P&ID development activities

The block flow diagram (BFD) is the preliminary document in the development of any CPI project. It outlines the most basic, general information related to the project. Then, it is the job of the process flow diagram (PFD) to add further details to the design before the final document — the P&ID — is developed (Figure 2). In general, the BFD captures the theoretical process steps that are needed to convert a feed stream to finished products while the PFD goes inside of each of the BFD "blocks" and shows the major types of equipment that are needed to meet the goal of each block. The BFD and PFD only show the main elements of the plant, while the

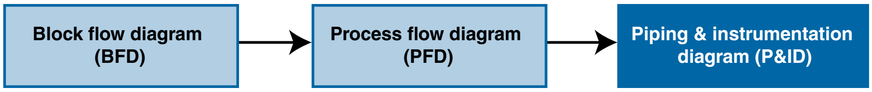


FIGURE 2. Before a detailed P&ID can be developed, a BFD and PFD must be developed to identify the major aspects of the process. The BFD identifies primary streams and unit operations. The PFD expands each BFD block, adding tanks, pumps and some instrumentation. The P&ID pulls it together with fuller details

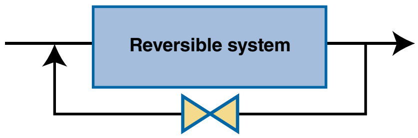


FIGURE 4. The startup of a reversible system often requires a recirculation loop; it should be sized appropriately to minimize costs

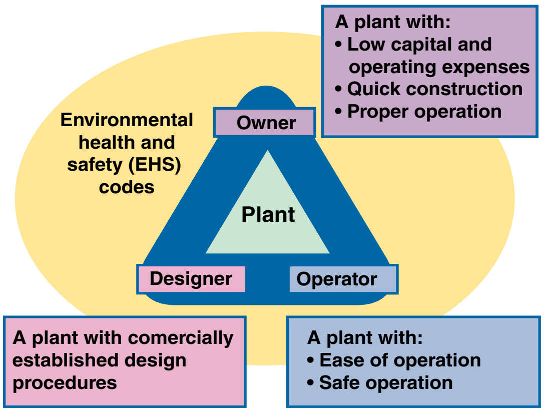


FIGURE 3. CPI facilities require cooperation among three parties. Each has its own responsibilities but EHS requirements are common to all

P&ID provides more detailed elements, capturing the real plant on paper while ignoring the scale.

Despite the simplified drawing shown in Figure 2, P&ID development goes beyond just expanding the PFD. There are some small items that are not shown but that need to be developed by the designer for the P&ID. Still, the development of the BFD and PFD requires exhaustive studies and rigorous calculations and simulations. Going through these "preliminary" efforts and not bypassing BFD and PFD development is essential, because every single decision for main items on the PFD could have a big impact on the project.

The main goal of a facility

The main goal of a process plant is to produce desired quantities of various products while meeting stated quality goals. A sound plant design will take into consideration the owner's wishes for the plant (for instance, low capital and operating expenses, the ability to build it quickly and so forth), the designer's requirements (that the design procedures can be trustworthy and commercially established) and the operator's requirements (to ensure ease of operation and flexibility), while meeting all local environmental and safety regulatory requirements (Figure 3).

Essential elements

Ideally, the specific elements captured in any P&ID should account for full functionality of the plant in all stages of the plant lifecycle, as outlined below:

1. All given elements — including equipment and piping items — must operate well and reliably during normal operation, within the window of operating conditions that is expected at the plant. A basic process control system (BPCS) should be implemented to bring parameters within normal conditions. The five key parameters of chemical process operations (temperature, pressure, flowrate, level and composition) may need to be "adjusted" continuously by the actions of the BPCS to ensure that they meet the requirements at the inlet and outlet of each component.
2. The element operates well during non-normal conditions, such as under reduced-capacity conditions, and during process upsets, startup and shutdown. Engineering provisions for working reliably during low-capacity operating conditions, the use of safety-instrumented systems (SIS) to shut down the system, and safety-relief valves are examples of the types of items that can address this stage of plant lifecycle in P&ID development activities.
3. There are enough provisions to ensure ease of inspection and maintenance; these include in-situ inspection, ex-situ inspection, workshop maintenance and more. All given elements must be designed to allow them to be appropriately isolated, drained, vented, cleaned and flushed (via purging, steaming, or water flushing).
4. Provisions must be made to minimize the impact on the rest of plant when an item, equipment or unit is out of operation.

The following points should be considered when adding different items to address any of the above four requirements:

1. Make sure that no added element within one stage of the plant's lifecycle will jeopardize another item's function. For example, adding bypass capabilities with a manual block valve for a safety-related switching valve (for the purpose of making the plant operational when the switching valve is out for maintenance, per Item 4 from the list above) could jeopardize the operation of the switching valve in an SIS; that is, the bypass could be left open and therefore create a safety flaw).
2. Decide if added items can be "merged" with each other or not. This basically involves checking if a single shared item can address multiple requirements within the plant lifecycle or not. Whenever possible, items should be "merged" or "shared" to make the most of capital and operational costs. In certain cases, this can be justified, especially when an item needs to be added for the purpose of satisfying Item 3 or 4 above. As these specific components are not in use all the time, a good process engineer will attempt to "merge" them with other items so they can carry out multiple functions.

However, this last practice cannot be carried out in all situations. From a redundancy point of view, it is not always good to expect one item to carry out multiple duties. Technically, one item could be time-shared when it is meant to carry out different duties at different times (that is, with no overlap in duty duration). When designing for shared duty, keep in mind that this setup may end up creating confusion among operators, may be more prone to cross-contamination, and may enable a small failure to lead to a big shutdown. Meanwhile, designing components to be dedicated (not shared) will drive up costs (if items are expensive), but they will be easier to troubleshoot, should a failure occur. One common example is the use of a manway pressure-relief valve (PRV) on one shared nozzle on tanks.

Typically, the ability to install shared items is most practical in batch systems and in systems with only intermittent operation. In such operations, a given item can be used for different duties during different time spans.

The following discussion explains the activities that are reqruied for P&ID development for each stage of a plant lifecycle.

1. Normal operation. For normal operation, each item on the P&ID needs to be able to carry out the duty it has been assigned. Since, in the majority of cases, this is not achievable through equipment design alone, a control system should be implemented on the equipment. The BPCS must ensure that the design of the equipment will force the equipment to operate within a "window" of expected results, typically at its best operating point.

In a broad sense, a control system is supposed to bring the five main process parameters — flowrate, pressure, temperature, level and composition — into the required range. "Composition" encompasses many relevant parameters, ranging from viscosity, density and conductivity to octane number and Brix number. All utility distribution and collection networks, and heat-conservation insulation, must also be decided at this stage.

2. Non-normal operation. Non-normal operations occur under the following conditions (Each is discussed below):

a. During reduced-capacity operation
b. During startup
c. During upset conditions

Reduced-capacity operation. Occasionally, actual plant capacity should be reduced from the design capacity for a variety of reasons. Such conditions may result from a shortage of raw materials or an excess of production, or from downtime of a critical equipment component or unit. The process engineer usually provides some turndown ratio (TDR) for the plant. TDR is a ratio between the normal capacity of the plant and the minimum running capacity that is possible without losing the quality of the product. TDR can be defined for the equipment, for a unit, or for the whole plant.

Some owners or operators expect the engineer to provide a TDR of around two for their plants (this means they want to be able to operate the plant at half capacity without losing any product quality). Some plant items (such as tanks) have an inherently high TDR, while others (such as equipment with internal weirs or vessels with internal feed distributors) have a lower TDR. The duty of the process engineer is to provide the required TDR (defined by the client) for each equipment component and for the entire plant.

One method of providing TDR is to install multiple smaller components in parallel, instead of one big piece of equipment. Another solution is to implement a recirculation loop around the equipment to compensate for the low flowrate.

Startup operations. Startup operation could be assumed to be a severe capacity-reduction case. Be cause process parameters during startup are not necessarily within their range, equipment and instrumentation are not expected to be working according to full operating expectations. However, startup specialists are often onsite in this stage and can help to compensate for the temporary lack of operability of equipment and instruments.

TABLE 1. OPTIONS FOR EQUIPMENT MAINTENANCE

	In-line	Off-line
In-place	By operators doing rounds	By the mechanical group
In workshop	Not applicable	

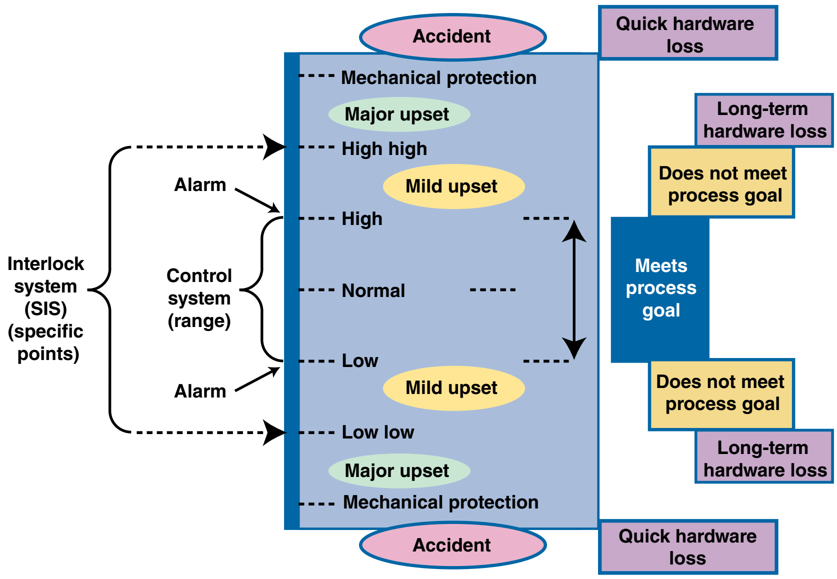


FIGURE 5. A diagram depicting upset conditions, such as this, can be defined for temperature, pressure, level, flowrate or composition of each component

TIPS FOR VENTS AND DRAIN VALVES

- Each drain can cover a portion of a system; Vents can cover a bigger portion
- Drain or vent size should be manageable (Minimum size should be ¾ in.; limit to 2 in., unless inside of dike)
- Multiple drains and vents should be implemented in a covered area to ensure draining or venting within a reasonable time
- When the system is small: drain = vent (usually for pipes <2 in.), and there is no need for dedicated vents or drains
- The drain or vent should be routed to a safe location (hard piped, if required)
- For volume < 0.5 m^3 (such as pump casings), use ¾-in. drains
- Vents can be one size smaller than the drain
- Drains for liquids with viscosity higher than 50 cP could be one size bigger than guidelines stated above

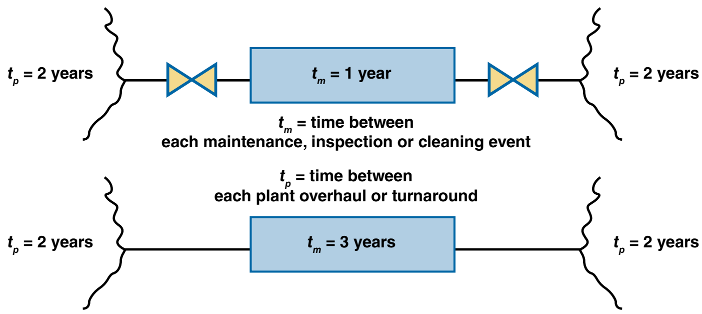


FIGURE 6. When planning for isolation valves, the engineering team should evaluate data related to the anticipated time for scheduled maintenance and anticipated turnaround schedules

TABLE 2. OPTIONS FOR ISOLATING A PORTION OF THE PROCESS FROM THE PLANT

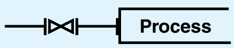
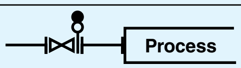
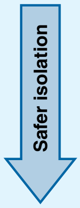
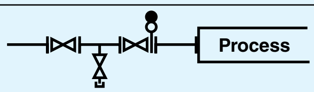
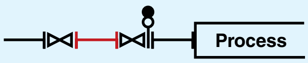
	Type	Symbol	Credibility
1	Block valve (with or without lock)		Not acceptable
2	Block valve (with lock) and blind		
3	Double block valve (with lock) and bleed		
4	Block valve (with lock) and blind and removable spool		

TABLE 3. DIFFERENT METHODS OF REMOVING MATERIAL FROM EQUIPMENT FOR INSPECTION OR MAINTENANCE

	Type of "dirt"	Removal method	P&ID
1	Solid/ semi-solid: removal	• Manual • Machine-assisted	• Nothing is needed on P&ID • Do we need "clean-out" doors?
2	Liquids: Washing	• Flushing: By water • Steaming out: By utility steam • Chemical cleaning: By chemical solution or solvents	For all the cases , three options are available to show on the P&ID: 1. Only washing valves 2. Washing valves that are hard piped 3. Hard piped washing system with switching valves for automatic washing
3	Gases: Purging	• Neutral gas purging • Ventilation	• If it is by inert gas, the same options for "washing" (above options) are available here • For ventilation (by natural draft of air), imake sure there are at least 2 nozzles are available

For reversible systems (such as reactors that carry out equilibrium reactions), startup operation can be supported by recirculation. If the system is not reversible, the startup operations can be more complicated and case-specific. Figure 4 shows the basics of this procedure.

If recirculation is to be used during the startup procedure, efforts should be made to avoid excessively large circulation loops, so as not to waste money for piping that is supposed to be used only during startup. As much as possible, the design should try to use the existing pipe arrangement for the purpose of startup recirculation, especially when high-bore pipe is needed to support startup efforts.

The tendency to use the piping arrangement that was implemented for normal operation for the purpose of startup recirculation is so strong that some process engineers forget to think about the startup operation during the development of the P&ID; they simply assume they will find a way to accommodate startup somehow without actually planning for it.

Upset conditions. Upset conditions can be defined as operation of the plant when some of the process parameters are beyond the normal band. In Figure 5, this situation is arbitrarily split into two different cases — mild upset and severe upset — for any of the five key parameters (flowrate, pressure, temperature, level, and composition). In both cases, during upset conditions, the process goals have already been lost so the immediate goal is to protect the equipment (hardware conservation) and the health and safety of the personnel and neighboring communities.

To address point upset conditions, the facility should be equipped with an alarm system and a SIS. The alarm setpoints are usually on the maximum (or minimum, in some cases) value of a parameter, and the SIS action will be set to the high-high (or low-low) level. However, some additional alarm setpoints or additional SIS setpoints can be added, too.

The purpose of this SIS action is to shut down a plant and bring it in the lowest energy state (in terms of lowest pressure, lowest temperature and so on) Other than "event-based SIS" explained above, SIS action(s) can also be activated by the operator. This shutdown is named "operator activated SIS."

TABLE 4. EXAMPLES OF REMOVABLE SPOOLS (RS)

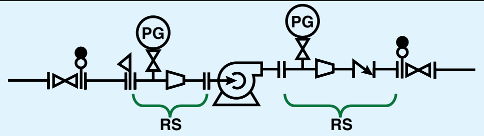
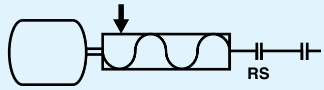
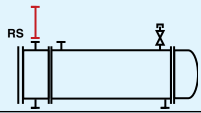
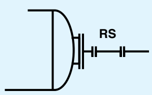
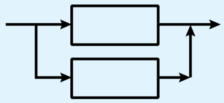
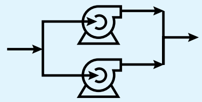
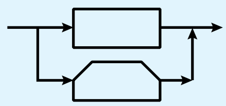
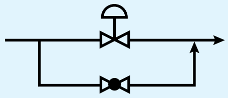
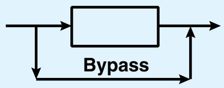
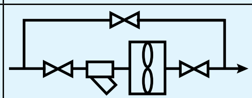
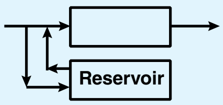
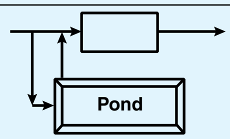
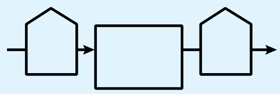
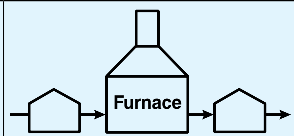
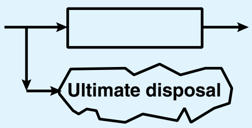
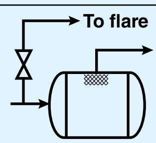
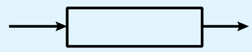
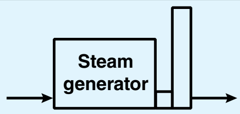
Item	Potential location of RS	P&ID example
Centrifugal pump	Suction and discharge side	
Progressive-cavity pump	Discharge side	
Shell-and-tube heat exchanger	Tube side	
Vessels and tanks	Lines out of flanged head or blinded nozzles	

TABLE 5. OPTIONS TO DEAL WITH LOST ITEMS IN A PLANT

Option	Schematic	P&ID example
The exact replica in parallel		
A similar item in parallel		
Bypassing the absent item		
Redirecting the in-flow to a "reservoir" for later use		
Upstream tank stores this inlet flow and the downstream tank provides outlet flow for a short period of time		
The inlet flow is sent permanently for ultimate disposal and the stream will be wasted		
The absence of an item doesn't generate any upset in the rest of plant or whole plant should be shut down		

The duty of the alarm is to warn the operator that something has gone wrong. If for whatever reason the operator fails to respond in a timely manner, the SIS system will initiate the action that the operator has failed to, or tried without success. This allocation of responsibilities between alarm system and SIS is shown in Figure 5.

If, for whatever reason, the SIS cannot mitigate the parameter that has deviated from the normal point and it has gone beyond high-high (or low-low) level, then finally a mechanical item needs to be triggered to "tame" the system and regain control. Even though a mechanical system (as the last line of defense) can be considered for each of the five parameters mentioned earlier, pressure safety valves (PSV) are a popular type of mechanical defense against a wild parameter. Installing PSVs, and routing their release to an appropriate destination, is an essential task during P&ID development.

Winterization is another issue that is resolved in this stage. Winterization involves implementing specific features in a plant design to prevent any impact of cold weather during a plant shutdown. For instance, winterization efforts typically start with provisions to enable "natural internal drainage" of the equipment and pipes more tolerant items, such as tanks. Other activities include heat tracing and insulation of pipes to prevent freezing or settling of non-drained (trapped) fluids, and installing fluid movers on emergency power sources to provide recirculation to prevent freezing/setting in the case of power loss.

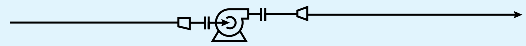
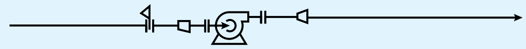
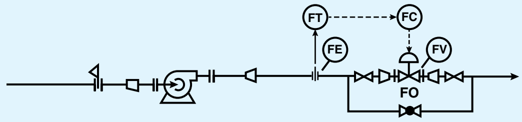
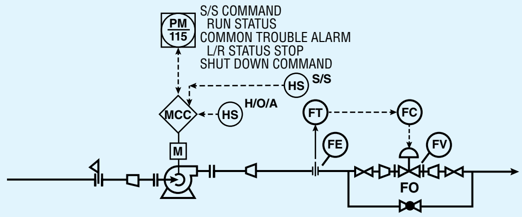
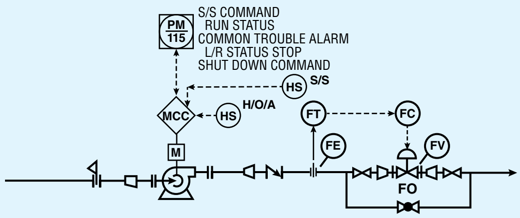
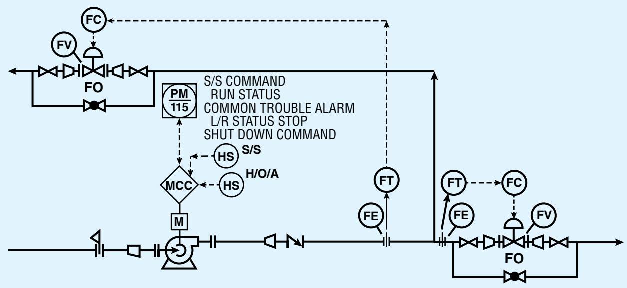
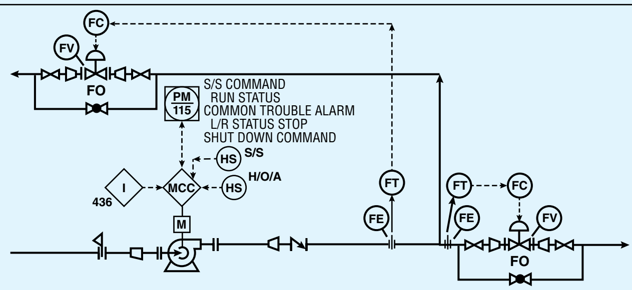
3. Inspection and maintenance. Equipment care can be categorized into "in-workshop" and "in-place" care, and the latter can be categorized further into "in-line" or "off-line" operation. In-place care is usually done by operators making rounds, while in-workshop care is typically carried out in a workshop by a mechanical group (Table 1).

Inline care can be considered the inspection of operation equipment, while off-line care is equipment repair or maintenance. Each requires different types of provisions for the equipment on the P&ID.

Operators making rounds could be equipped with portable sensors; if not, then he or she must rely on the use of the senses:

- Sight: To observe, for instance, leakage, vibration, overflow of tanks, fluid levels, flame color and shape
- Sound: To sense vibration, cavitation, hammering, PSV release, explosion and more by listening
- Touch: To detect vibration
- Smell: To detect fire, leakage, PSV release to atmosphere, and more

To support the work of the operator making rounds, specific items can be put on the P&ID. These may include sight glasses to check liquid levels, catalyst levels or filtering-

TABLE 6. AN EXAMPLE OF P&ID DEVELOPMENT FOR A PUMP (FOUR PHASES OF OPERATION)	
Case	**P&ID**
Normal operation	
Putting the pump call-out with the required information on top of P&ID sheet	Call-out should be put on P&ID
Placing a reducer/expander to match suction and discharge side of the pump, if needed (may need a top-flat eccentric reducer at connection)	
Adding a permanent strainer to prevent damage to the pump	
Making sure the suction pressure (and temperature) is enough. This reflects the sensitivity of centrifugal pumps towards NPSH	It needs some calculations. The impact on P&ID could be seen on suitable in upstream container of pump
Showing the pump's BPCS for capacity control of pump	
Adding pump driver control	
Non-normal condition	
Considering a temporary strainer (commissioning)	A permanent strainer is already placed
Adding a non-returning valve in the case of reverse flow	
Using the minimum flow line on the discharge line with a control valve to protect the pump from flows that are lower than the minimum flow of the pump	
Showing the pump SIS and/or alarming system to protect the pump from an abnormal condition (one example is a monitoring system for seal leakage)	

Continues on pg. 69

media levels, or peep holes to check the color and shape of flames in a furnace or boiler.

In terms of the use of small, portable measuring devices that can be used by operators making rounds, these may include portable pressure gages, temperature sensors and so on. The P&ID designer may decide to provide some "test points" instead of fixed gages, to save some money in non-critical points. This may include, for example, a pressure tapping (PT) point, or temperature point (TP), to be shown on the P&ID. An example of PT location could be the suction side of centrifugal pumps. The decision must be made to either use test points and fixed gages that transmit information to the control room, or to implement a control loop that depends on some parameters based on the criticality of the parameter.

Meanwhile, in-place, off-line care may include chemical or solvent cleaning, steaming-out, pigging operations and so on. Depending on the operation-specific requirements, different items should be implemented (such as chemical cleaning of valves).

For all off-line care a specific arrangement must be made to ensure positive isolation of the system from the rest of the plant. This arrangement typically comprises isolation valves, drains, vent valves and so on. The isolation system is discussed in greater detail below.

For in-workshop care, the provisions defined by in the P&ID are items that will allow the equipment to be removed from their foundation easily and safely. However, the characteristics to satisfy this requirement are not always shown on P&IDs (mainly to avoid cluttering of the P&ID). For example, if equipment needs to be hoisted for removal, this engineering detail is often not shown in the P&ID. Items that must be shown on the P&ID include the following:

- Isolation valves that allow the equipment components to be detached from the rest of the plant
- Drains and vents
- Removable spools (RS) that would be used around the equipment to allow it to be "untangled" from the system by removing the piping system interference; this allows for easy equipment transfer to the workshop

When it comes to preparing for off-line care, with regard to designing isolation systems, the following three questions should be answered:

1. To which equipment should the isolation elements be added?
2. Where do they need to be placed "around" the equipment?
3. Which types of isolation systems or elements should be used?

To answer the first question, providing isolation valves is not necessary for all the equipment in a plant. Isolation valves are required to isolate the equipment from the rest of the plant if the equipment is expected to need "off-line care" at frequent intervals, in time durations that are shorter than the scheduled plant turnaround times). For instance, if (based on historical data), the unit expects to need off-line care every three years but the entire facility for which you are developing the P&ID will need planned turnaround work every two years, there is no need (at least theoretically) to put isolation valves upstream and downstream of the unit. This concept is shown in Figure 6.

In some cases, companies don't provide isolation systems for essential equipment, such as heat exchangers. The logic is that they essentially cannot afford to put the heat exchanger out of service, so adding isolation valves would be irrelevant.

The answer to the second question is that the isolation system should be added on all downstream or upstream connecting pipes, as close as possible to the equipment. However, some companies challenge this and question if there is real needed to put isolation valves on, for example, a vent pipe to atmosphere or not.

To answer the third question, it should be stated that there are different type of isolation systems. Table 3 summarizes these methods.

Decision needs to be made about the type of isolation method. The isolation method depends on factors, such as the equipment environment (for instance, for confined spaces or non-confined spaces), the fluid type (aggressive or toxic or not), and the pressure and temperature of the system. Usually the first type of isolation (Table 2) does not provide enough "positiveness." Possibly the only application of this isolation method is for instruments. In such an application, the isolation valve is called a root valve.

The next step for making equipment ready for periodic removal is to bring it to "non-harmful conditions." This means having provisions that will allow all five key process parameters to be brought into a safe range:

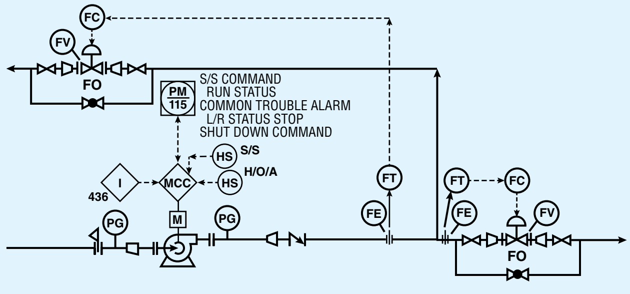
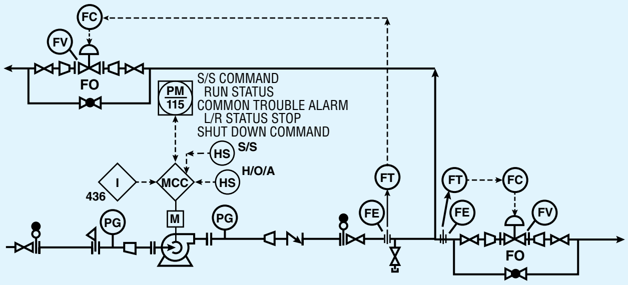
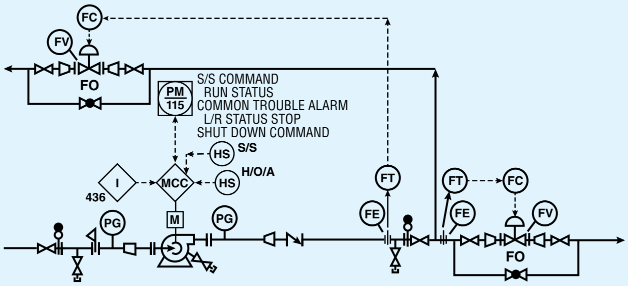
- Ensuring safe temperatures: Options include allowing time lapses, or options for cooling down (or warming up, in the case of cryogenic services) streams. For some systems (for instance some batch operations) that require a more rapid cooling (or warming) by cooling streams
- Making pressure safe: Venting is widely used
- Ensuring appropriate flowrates: As long as equipment is isolated from the rest of the plant, there is no flow going into it, and it is not a point of concern
- Making levels safe: Drainage options are needed for tanks, vessels, pump casing and more. Some general rules for sizing and installing drain and vents are in the Box (p. 65)
- To ensure safe compositions, the body of the equipment (external and/or internal) must be safe in terms of exposure. These provisions involve proper cleaning of the equipment.

  Table 5 shows options for making the composition safe for different types of materials inside of the equipment. Washing and purging (through ventilation) are especially important for walk-in equipment.

The last step as mentioned above is to provide removable spools (RS). Sometimes required RS are already present due to previous activities on the P&ID. Table 4 provides some examples.

Allocating a utility station in different locations of the plant, and deciding about the required utilities for each utility station, is another activity to address this stage of the plant lifecycle.

4. Operability of the plant in the absence of one item. The designer needs to decide the impact of equipment loss on the rest of plant operations and take engineering steps to minimize its impact. The wide range of answers and decisions should include the following:

TABLE 6. AN EXAMPLE OF P&ID DEVELOPMENT FOR A PUMP (FOUR PHASES OF OPERATION) (continued)	
Case	**P&ID**
Maintenance / Inspection	
Adding a pressure gage on discharge and/or suction side	
Adding block valves in the suction and discharge line (such as a gate valve) in order to isolate the pump during maintenance	
Consider vent and drain valves in the pump suction and discharge sides and in the pump casing	
Consider the use of a piping spool piece to facilitate dismantling	It is already created and exists
Installing pump insulation for personal protection	Service temperature is 40°C and there is no need for personnel protection insulation
Production interruption	
Define the pump sparing philosophy	Based on RAM analysis, a second pump with the same arrangement is added (to provide 2 x 100% capacity)

1. A parallel, exactly similar spare system can take care of flow that would result from the loss of a given component. Examples include spare pumps or spare heat exchangers (in highly fouling services). The installation of spare equipment is popular for fluid-moving equipment, since interruption of service in pumps and compressors cannot be handled through other below options. One important example is having two fire pumps installed in parallel, with two different types of drives (for instance one with an electromotor and the other using a diesel drive pump).
2. A parallel component can be used and the flow can be redirected to the alternate component instead. Examples include having a manual throttling valve (such as a globe valve) in the bypass line of a control valve, or placing a bypass line for a PSV together with a pressure gage (or pressure tapping) and a globe valve.
3. The feed to the equipment can be simply bypassed temporarily with marginal impact on the operation of the system.
4. The feed to the equipment can be redirected temporarily to an "emergency reservoir" (such as a tank or pond), and processed later by returning it back to the system. Usually this option is available for liquid streams.
5. The storage tanks upstream and downstream of the component should have enough residence time to continue operations. This way, if the component goes out of service, the upstream string of equipment can still feed the upstream tank and downstream components can still be fed by the downstream tank. This arrangement will prevent a surge that could impact connected plant components.
6. The feed to the equipment is redirected temporarily to a waste-receiving system or flare.
7. Whole plant or unit should shut down: This option should be avoided, if possible. However,

sometimes this is inevitable when the equipment of interest is a key asset in the facility.

Table 5 summarizes these options for a P&ID.

Spare pump options

While the discussion below focuses on pumps, the guidelines apply to any other types of spare equipment as well. A spare pump, depending on the criticality of the service, could be "an installed spare" or "a workshop spare." A workshop spare pump is not installed but can be moved from the workshop and deployed within a short period of time (say, 24 hours).

Decisions related to any of the above two options (in terms of installed spares or workshop spares) can be based on different parameters, including the following:

- Mean time between failure (MTBF) of the equipment
- Mean time to repair (MTTR) of the equipment
- Cost of maintenance
- Value of the "lost production"

For installed spares, if the ambient temperature of the space around the a pump is far from the operating temperature of the pump (for instance, differs by 100 to 150°C), the pump should be "a hot standby pump" (or "a cold standby pump" for cryogenic service) to make sure it will not experience thermal shock during the startup. Otherwise the pump could be installed with no specific "stand-by provisions."

If a spare pump is supposed to "sit" beside more than one operating pump, another feature that should be decided is whether the spare pump is a common spare (to be available for several operating pumps), or is intended for use with just one dedicated pum; thus a spare should be installed for each operation pump.

For spare pumps, the user might expect that all pumps should be able to act as both an operating pump and a spare pump for any of other pumps that may be out of service (where no specific spare pump has been designated). When providing common (shared) spare pumps (that may need to periodically function as spare pumps for all other pumps), the specific piping arrangements around the pumps will need to be elaborated on the P&ID.

Table 6 shows an example of P&ID development for a pump in one case. This table only provides the required thought process for the development of a pump P&ID as an example.

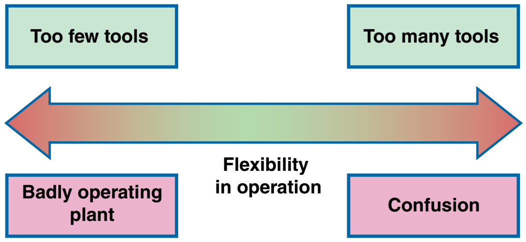


FIGURE 7. A balance must be sought between "too much" and "too little" when developing the engineering details for a P&ID

Additional important items

In addition to the last four stages of the lifecycle of a plant (discussed above), a few other items must be considered:

Future plans. If there is any plan for expansion, or any prediction for implementing new, under-review innovations in future, this needs to be addressed in the P&ID to facilitate the implementation of the future changes with minimum impact on the operating plant.

Insulation to safeguard personnel. Equipment and pipes with skin temperatures that are greater than 60–75°C (especially for metallic items), and those that are located in crowded areas within reach of workers, must be insulated. This insulation is called personnel protection (PP) insulation on the P&ID.

Useful rules-of-thumb

Whether the design engineer (in the role of P&ID developer) is capturing general items (such as containers, fluid movers, heat exchangers and so on) or more specialized items (such as liquid-extraction towers, filter press and so on), these general rules-of-thumb can help:

1. Much of the equipment that we buy for any given plant is not "custom built equipment," so we cannot expect the components to operate exactly according to the desired operating points. Even for the case of custom made items, we usually expect that the equipment will operate in a pre-determined "window" of operation. The result is that almost all equipment in CPI facilities should be brought closer to the desired operating point through the use of a control system. Key parameters that must be controlled include flowrate and head for pumps, and heat duty for heat exchangers.
2. Check the required temperature and, pressure for each item (inlet and outlet) and make sure these are matched with process needs. If they are not matched, take action to address them.
3. Check the required flowrate for each item. What is the minimum flowrate that can be handled without negative impact on the process, and what is the minimum flow that can be accommodated before there is potential harm to the equipment? If there is a chance of harm from low flow, then plan accordingly to protect the equipment from it.
4. Check the required composition of the streams going into the equipment and note the special care that should be taken. For example, a positive-displacement pump is prone to plugging if the liquid contains large suspended solids. In this case, a strainer should be installed.
5. Be sure to account for the required utilities and their temperatures and pressures.
6. What are the weak points of the item and what requirements should be taken when designing a proper SIS system for the item?
7. Which parameters must be monitored by the operator making rounds? Think about the five key parameters: Temperature, pressure, level, flowrate and composition.
8. Be sure to acknowledge which as-

pects of each component need inspection or monitoring.

9. Review any history of item failures (in terms of frequency and time for maintenance) and act accordingly to address them.
10. Consider the impact of an item going out of service. What steps can be taken to minimize the impact of this on the rest of the plant? Is it possible to have a similar system as a spare?

Common challenges

During the development of a P&ID, the need to choose between competing options is a common challenge. Here are several common scenarios:

"Should I show a given detail on the main body of P&ID by a schematic, or can I capture it in the note area?" The P&ID is a pictorial diagram. As much as possible, the P&ID should capture relevant schematic shapes.

"Should I add the item or not?" Items should be added to give required flexibly to the operator. A plant with insufficient "facility resources" is difficult to operate.However, from the other side, this is also the case for a plant with more than enough pipe circuits, control valves, alarms and SIS actions. For example, a plant with too many alarms can "overload" the operator and result in a loss of urgency from the operator when an alarm does activate (Figure 7).

"Adding more doesn't hurt." This is a popular statement when P&ID developers try to "bypass" conducting a rigorous evaluation for the necessity of an item on the system, and thus place it with no real necessity. However, designers should remember that in some cases, adding an item might not necessarily increase the capital cost of the project — if the item is small and relatively inexpensive — but may still increase the operating cost because of required inspection, maintenance, related utility and chemical usage and more. In addition to that, any new item added to the system provides a new opportunity for mistakes, cross -contamination, leaks and other problems.

"Should I add it here on the P&ID or will it be captured in other documents?" The P&ID is supposed to be a common document that can be used by quite a few different disciplines. Incompleteness is an inherent feature of it. Furthermore, the P&ID is supposed to be kept in the plant, for easy use by operators. If it is too cluttered, its usefulness is diminished.

Generally speaking, all process equipment should be shown in P&IDs. Sometimes, non-process related P&IDs (such as gearboxes and lubrication systems) should also be shown on the main P&ID or on auxiliary P&IDs. Meanwhile, if they are not shown on P&IDs, their details can be found in vendor documents.

All pipes and pipe appurtenances except bends and elbows are shown on P&IDs. Flanges should be depicted, if there is a specific reason for them. Specific piping items that are not shown on the P&ID can be found on piping models.

When it comes to instrumentation and control system, things become more debatable. The three main items of integrated control and safety system (ICSS) elements are: Regulatory control system (BPCS), the alarm system and the SIS. Almost everyone agrees about basic process control items should be shown on the P&IDs. They are mainly the elements of the control loops. For alarming systems, the same clarity exists. The main debate is usually on SIS systems, in terms of the question of "down to which level of detail the safety interlock loops should be shown on the P&IDs?"

Different companies follow different directions.

"Based on my past experience..." The inherent creativity required in creating P&IDs may become hindered, if for every single case one refers to "past experience." As unlikely as it may seem, the "this is what has been done before" mentality is not the most efficient way of developing this document. That being said, the technological innovations, availability of materials, quality of raw materials, required quality of products, capacity of the system, and ambient temperatures and pressures will most likely differ for each new project. When developing P&IDs, a previously effective method may be entirely ineffective in the current project, while a method that has proven useless in the past may work perfectly well this time around. ■

Edited by Suzanne Shelley

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A better look into kettle reboilers

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

In my October 2011 column (A window into kettle reboiler secrets, *Chem. Eng.* p. 28) I briefly described FRI's early work using two windows on its industrial-size kettle reboiler. Subsequent to that, FRI had performed appreciable heat-transfer work. All of that work was reported to FRI's members at all-day kettle-reboiler symposia, which were held in Galveston, Tex. on October 2 and in Tokyo on November 20 (both 2013). All of the feedback that was received during those meetings was documented and considered. Another symposium will be held in Ludwigshafen, Germany, on September 25, 2014. Professors Ken Bell and Rob Whiteley of Oklahoma State University, who were mentioned in the October 2011 column, continue to consult for FRI regarding heat transfer work.

During the last two years, one of FRI's focus areas was the entrainment of liquid droplets out of the vapor product nozzle. FRI added two new windows to the kettle, at the steam-header end of the heat exchanger. Entrainment is now visible from four different windows. Tracerco (Pasadena, Tex.; www.tracerco.com) personnel have collected gamma-scan data from the vertical and horizontal sections of the vapor-product piping. Those data were easily converted to liquid entrainment data [liquid(L)/vapor (V) basis]. Pressure drop data were collected across that same piping and were compared against theoretical calculations. When the kettle was entrainment-flooded, according to visual observations, the measured pressure drops deviated from (became higher than) the theoretical values.

Subsequent to the 2011 column, appreciable data were collected regarding boiling pool depths and maximum horizontal vapor velocities, in other words, the points at which excessive liquid droplets were swept up from the boiling pool. Tony Cai developed a boiling-pool depth correlation; the impact of steam rate (reboiler duty) was surprisingly weak. Cai also developed a maximum, horizontal vapor-velocity correlation. Both of those correlations were applied to a literature kettle flood point (Kister, H.Z. and Chavez, M.A., Kettle Troubleshooting, *Chem. Eng.*, February 2010, pp. 26–33). Cai's correlations successfully predicted that industrial experience.

On four separate occasions, FRI attempted to run its kettle in "semi-thermosiphon mode." Specifically, the liquid level in the bottom of the column was raised until the vapor return nozzle (from the kettle) was completely flooded with liquid. FRI's column has windows placed exactly opposite the kettle vapor-return nozzle. Video footage of that liquid-submerged nozzle was "amazing." This semi-thermosiphon mode of operation was performed with three different binary systems across a broad range of pressures. The column proved to be easily controllable. Windows farther up on the column were used to assure that the liquid level in the bottom of the column was not so high as to reach the packings that were located farther up in the column.

FRI engineers will present a paper regarding this work on April 2 at the AIChE Spring Meeting (New Orleans, La.; www.aiche.org). Video footage will be shown. ■

Mike Resetarits

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53 Valves
54 Engineering Computers/Software/Peripherals
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7	22	37	52	67	82	97	112	127	142	157	172	187	202	217	232	247	262	277	292	307	322	337	352	367	382	397	412	427	442	457	472	487	502	517	532	547	562	577	592
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15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360	375	390	405	420	435	450	465	480	495	510	525	540	555	570	585	600

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People

APRIL WHO'S WHO

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Bühler Aeroglide (Cary, N.C.), a manufacturer of engineered thermal-process systems, names *Hans-Jörg Ill* president and CEO.

Detlev Rose becomes chief sales officer at **Beumer Group GmbH & Co. KG** (Beckum, Germany) a manufacturer of packaging, sorting, loading and conveying systems.

CRP Industries (Cranbury, N.J.), a maker of high-pressure specialty hoses, belts and motors, names *Caitlin Travers* senior applications engineer.

Pump Solutions Group (PSG; Oakbridge Terrace, Ill.), makes the following appointments: *David Wang* becomes president of PSG Asia, *Karl Buscher* becomes president of PSG Americas; *Ueli Thuerig* becomes president of PSG Europe, Middle East, Africa (EMEA); and *Carrie Halle* becomes director of marketing, Americas.

Scott Corbin is named regional manager, compliance, for **Integrated Project Services** (IPS; Blue Bell, Pa.), an engineering, construction and commissioning firm.

Bal Seal Engineering (Foothill Ranch, Calif.), a designer of custom sealing, connecting, conducting and EMI-shielding components, appoints *Sarah Smith* global market manager for analytical products.

ValvTechnologies, Inc. (Houston) promotes *David Bowden* to managing director of its wholly owned subsidiary MCE Group plc, a master valve distribution, modification and service facility based in Stockton-on-Tees, U.K. ■

Suzanne Shelley

BUSINESS NEWS

PLANT WATCH

ExxonMobil to construct butyl rubber and hydrocarbon resin plants in Singapore
March 6, 2014 — ExxonMobil Chemical Co. (Houston; www.exxonmobilchemical.com) plans to build facilities to manufacture halobutyl rubber and hydrogenated hydrocarbon resin at its petrochemical complex in Singapore. Engineering and procurement activities have begun, with construction expected to begin in the second half of 2014. Completion is anticipated in 2017 for the project, which will add production capacity of 140,000 metric tons per year (m.t./yr) of halobutyl rubber and 90,000 m.t./yr of hydrogenated hydrocarbon resin.

BASF breaks ground on new resin and coating facility in Shanghai
March 6, 2014 — BASF SE (Ludwigshafen, Germany; www.basf.com) broke ground on a new resin and electrocoat plant at the Shanghai Chemical Industry Park. With its operation scheduled to commence in the second half of 2015, this new resin and electrocoat plant will be located adjacent to another new BASF automotive coatings plant, which will start operation in 2014.

AkzoNobel doubles capacity for industrial coatings in China
March 5, 2014 — Akzo Nobel N.V. (Amsterdam, the Netherlands; www.akzonobel.com) has completed the expansion of its Industrial Coatings site in Songjiang, China, doubling its annual production capacity. Work started in 2012, when around €14 million was invested in the facility.

WorleyParsons awarded Canadian bitumen-refinery project
March 5, 2014 — WorleyParsons Ltd. (North Sydney, Australia; www.worleyparsons.com) will provide detailed engineering and procurement services for the tankfarm, piperack and flare units of Phase 1 of the North West Redwater Partnership's greenfield bitumen-refinery project, located in Sturgeon County, in Alberta's Industrial Heartland area. Commercial operations are targeted for September 2017.

Huntsman opens new thermoplastic polyurethanes production facility
February 27, 2014 — Huntsman Corp. (The Woodlands, Tex.; www.huntsman.com) has officially opened its new thermoplastic polyurethanes (TPU) production facility at the Jinshan Second Industry Zone in Shanghai. The $20-million plant is Huntsman's first TPU production facility in the Asia-Pacific region.

Styron increases latex production capacity with new reactor in China
February 26, 2014 — Styron Europe GmbH (Horgen, Switzerland; www.styron.com) has announced plans to expand its latex capacity with a new reactor at its Zhangjiagang, China production facility. The new reactor, expected to begin production in the second quarter of 2015, will be Styron's fourth unit of its kind at Zhangjiagang.

Kaneka to build manufacturing plant for acrylic fibers in Malaysia
February 18, 2014 — Kaneka Corp. (Osaka, Japan; www.kaneka.com) will establish a new manufacturing facility for acrylic fibers at Kaneka's existing site in Pahang State, Malaysia. With a production capacity of 12,000 m.t./yr, the facility's capital investment was approximately $88 million. Operations are expected to begin in October 2015.

Ineos expands capacity for ethylidene norbornene at Antwerp site
February 14, 2014 — Ineos Technologies (Rolle, Switzerland; www.ineos.com) has expanded its ethylidene norbornene (ENB) plant at its Antwerp facility, increasing its capacity to 28,000 m.t./yr, and making it the largest ENB plant in the world, according to the company.

MERGERS AND ACQUISITIONS

FMC announces separation into two independent companies
March 10, 2014 — FMC Corp. (Philadelphia, Pa.; www.fmc.com) has announced plans to separate into two independent public companies, "New FMC," which will be comprised of FMC's Agricultural Solutions and Health and Nutrition segments and "FMC Minerals," which will be comprised of FMC's current Minerals segment. FMC Corp. expects to complete the separation in early 2015.

Evonik acquires Michigan-based silane producer Silbond
March 4, 2014 — Evonik Industries AG (Essen, Germany; www.evonik.com) has acquired Silbond Corp. (Weston, Mich.; www.silbond.com), a supplier of silicic acid esters, a special group of functional silanes used in a wide variety of applications, including coatings and electronics.

Kemira acquires BASF AKD emulsion business
February 27, 2014 — Kemira Oyj (Helsinki, Finland; www.kemira.com) and BASF have announced that Kemira will acquire BASF's global alkyl ketene dimer (AKD) emulsion business. The transaction is expected to close in the first half of 2014.

Vitol to purchase Shell's Australian downstream businesses for $2.6 billion
February 21, 2014 — Royal Dutch Shell plc (The Hague, the Netherlands; www.shell.com) has agreed to sell its Australia downstream businesses (excluding Aviation) to The Vitol Group (Rotterdam, the Netherlands; www.vitol.com) for around $2.6 billion. The sale covers Shell's Geelong Refinery and retail business, along with its bulk fuels, bitumen, chemicals and part of its lubricants businesses in Australia.

Toray and Abunayyan launch water-treatment JV in Saudi Arabia
February 21, 2014 — Toray Industries Inc. (Tokyo, Japan; www.toray.com) and Abunayyan Holding (Riyadh, Saudi Arabia) have launched a joint venture (JV) for water- and wastewater-treatment technologies. The JV will be called Toray Membrane Middle East LLC (TMME). The projected investment for the JV is $80 million.

Ineos and Sinopec form JV for new phenol acetone plant in China
February 20, 2014 — Ineos Technologies and Sinopec YPC have agreed to form a 50/50 JV called INEOS YPC Phenol (Nanjing) Company Ltd. The JV will build a phenol acetone plant in China, due to be completed at the end of 2016, with a total investment of approximately $500 million. The production capacity of the new plant will be at least 400,000 m.t./yr of phenol and 250,000 m.t./yr of acetone. It will also include 550,000 m.t./yr of cumene capacity.

AMEC acquires Foster Wheeler for $3.3 billion
February 13, 2014 — Foster Wheeler AG (Zug, Switzerland; www.fwc.com) has announced that it has entered into a definitive agreement with AMEC plc (London, U.K.; www.amec.com) in which AMEC will acquire all shares of Foster Wheeler, for a total value of approximately $3.3 billion. The transaction is expected to close in the second half of 2014. ■

Mary Page Bailey

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Economic Indicators

2012 — 2013 — 2014

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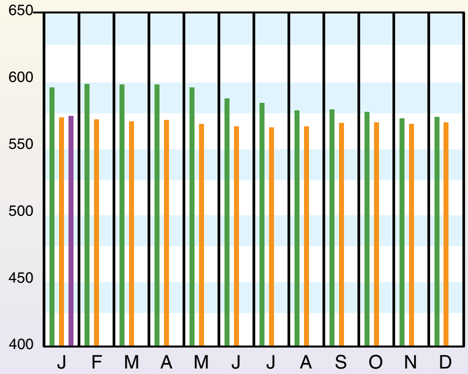
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Jan.'14 Prelim.	Dec.'13 Final	Jan.'13 Final
***CE* Index**	572.6	567.5	571.2
Equipment	695.6	687.9	692.8
Heat exchangers & tanks	632.6	621.6	630.1
Process machinery	657.4	656.0	657.6
Pipes, valves & fittings	883.5	875.7	890.4
Process instruments	412.8	412.5	416.5
Pumps & compressors	928.7	925.8	913.9
Electrical equipment	515.4	513.8	513.3
Structural supports & misc	762.3	746.9	741.6
Construction labor	317.7	318.7	319.2
Buildings	537.6	532.8	530.9
Engineering & supervision	321.9	322.0	326.8

Annual Index:

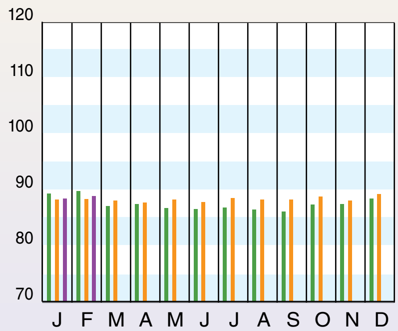
2006 = 499.6
2007 = 525.4
2008 = 575.4
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3



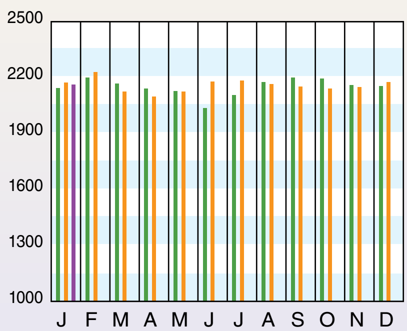
CURRENT BUSINESS INDICATORS*

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2007 = 100)	Feb.'14	=	88.8	Jan.'14	=	88.4	Dec.'13	=	89.2	Feb.'13	=	88.0
CPI value of output, $ billions	Jan.'14	=	2,161.8	Dec.'13	=	2,176.6	Nov.'13	=	2,149.0	Jan.'13	=	2,173.3
CPI operating rate, %	Feb.'14	=	74.8	Jan.'14	=	74.5	Dec.'13	=	75.2	Feb.'13	=	74.7
Producer prices, industrial chemicals (1982 = 100)	Feb.'14	=	299.6	Jan.'14	=	294.0	Dec.'13	=	294.2	Feb.'13	=	315.8
Industrial Production in Manufacturing (2007 = 100)	Feb.'14	=	97.2	Jan.'14	=	96.4	Dec.'13	=	97.2	Feb.'13	=	95.7
Hourly earnings index, chemical & allied products (1992 = 100)	Feb.'14	=	156.7	Jan.'14	=	157.6	Dec.'13	=	158.3	Feb.'13	=	155.0
Productivity index, chemicals & allied products (1992 = 100)	Feb.'14	=	107.7	Jan.'14	=	106.6	Dec.'13	=	108.1	Feb.'13	=	103.8

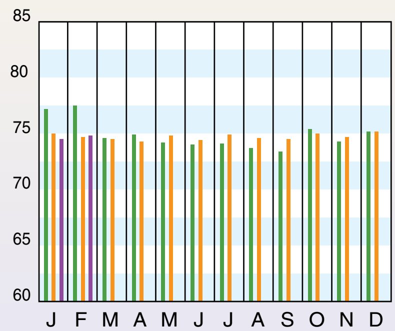
CPI OUTPUT INDEX (2007 = 100)



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

HIGHLIGHTS FROM RECENT ACC WEEKLY REPORTS

In its recent Weekly Economic and Chemistry reports, the American Chemistry Council (ACC; Washington, D.C.; www.americanchemistry.com) discussed data from the JPMorgan Global Manufacturing PMI (purchasing manager's index), among a host of other items. The Global PMI rose 0.3 points to 53.3 in February, a 34-month high. The global PMI has signaled expansion in each of the last 15 months, and has maintained a generally upward trend since April. However, says the report, disparities remain between the developed nations and emerging markets.

"Growth continues to be stronger in the United States and the Euro Area, and the upturns in Japan and the United Kingdom remain robust," the ACC said, but continued, "In contrast, the PMIs for China, South Korea and Russia signal contraction, while rates of growth in Brazil and India were below the global average."

Other economic data in the ACC reports suggested that wholesale trade in chemicals grew 1.4% in the U.S. in January, to $10.8 billion, while inventories fell 1.3% to $12.6 billion.

And in January, U.S. specialty chemicals market volumes fell 0.7%. The decline in January follows a 1.1% gain in December and a 0.5% gain in November. The severe winter weather experienced by much of North America in January is clearly having an effect on markets, ACC said.

Of the 28 specialty chemical segments in the U.S. monitored regularly by ACC, only 4 expanded in January. By contrast, 25 and 23 segments expanded in December and November of last year, respectively.

Meanwhile, the Organization for Economic Co-operation and Development (OECD; Paris; www.oecd.org) released its composite leading indicator (CLI) for January, and the data indicate that the CLI for the OECD+6 (OECD member countries plus six major non-member economies) held steady in January. ❑

CURRENT TRENDS

The annual 2013 *CE* Plant Cost Index (CEPCI; top) is available, and stands at 3.0% lower than the 2012 annual average value. However, the initial numbers for 2014 (January 2014 preliminary) generally increased from the final December index values from 2013. Compared to a year ago, the PCI index for January 2014 is 0.24% higher — marking the first time in nearly two years where the more recent number was higher than the corresponding year-earlier index value. Meanwhile, updated values for the Current Business Indicators (CBI) from IHS Global Insight (middle) saw the CPI output index edge higher compared to the previous month, while the CPI value of output index decreased slightly. ❑

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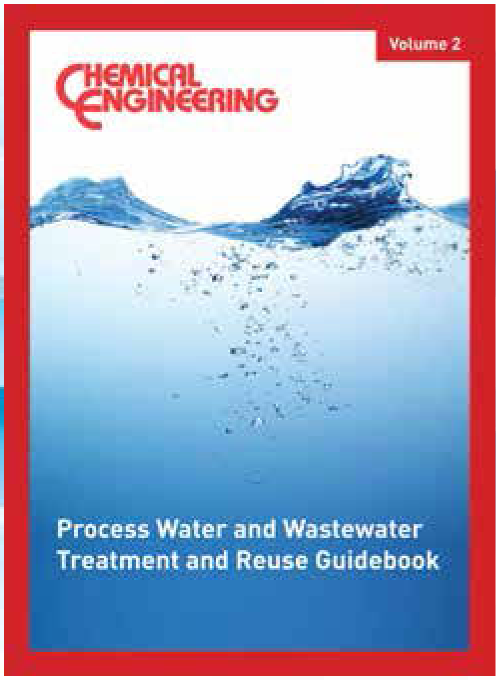
Process Water and Wastewater Treatment and Reuse Guidebook- Volume 2



This guidebook contains how-to engineering articles formerly published in *Chemical Engineering*. The articles in Volume 2 provide practical engineering recommendations for process operators faced with the challenge of treating inlet water for process use, and treating industrial wastewater to make it suitable for discharge or reuse.

There is a focus on the importance of closed-loop or zero-discharge plant design, as well as the selection, operation and maintenance of membrane-based treatment systems; treating water for use in recirculated-water cooling systems; managing water treatment to ensure trouble-free steam service; designing stripping columns for water treatment; and more.

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